

# BEST AVAILABLE COPY

<b>(12) PATENT</b>		<b>(11) Application No. AU 200059214 B2</b>	
<b>(19) AUSTRALIAN PATENT OFFICE</b>		<b>(10) Patent No. 776580</b>	
<b>(54) Title</b> <b>Two-step radial expansion</b>			
<b>(51)<sup>7</sup> International Patent Classification(s)</b> <b>F16L 055/16</b>			
<b>(21) Application No: 200059214</b>		<b>(22) Application Date: 2000.07.07</b>	
<b>(87) WIPO No: WO01/04535</b>			
<b>(30) Priority Data</b>			
<b>(31) Number</b>	<b>(32) Date</b>	<b>(33) Country</b>	
<b>60/143039</b>	<b>1999.07.09</b>	<b>US</b>	
<b>60/146203</b>	<b>1999.07.29</b>	<b>US</b>	
<b>(43) Publication Date : 2001.01.30</b>			
<b>(43) Publication Journal Date : 2001.04.12</b>			
<b>(44) Accepted Journal Date : 2004.09.16</b>			
<b>(71) Applicant(s)</b> <b>Shell Internationale Research Maatschappij B.V.</b>			
<b>(72) Inventor(s)</b> <b>Robert Lance Cook; David P. Brisco; R. Bruce Stewart; Reece E. Wyant; Lev Ring; James Jang Woo Nahm; Richard Carl Haut; Robert Donald Mack; Alan B. Duell; Andrei Gregory Filippov</b>			
<b>(74) Agent/Attorney</b> <b>Davles Collison Cave, Level 15, 1 Nicholson Street, MELBOURNE VIC 3000</b>			
<b>(56) Related Art</b> <b>US 5787933</b> <b>US 5368075</b>			

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
18 January 2001 (18.01.2001)

PCT

(10) International Publication Number  
WO 01/04535 A1

(51) International Patent Classification<sup>7</sup>: F16L 55/16

(21) International Application Number: PCT/US00/18635

(22) International Filing Date: 7 July 2000 (07.07.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
60/143,039 9 July 1999 (09.07.1999) US  
60/146,203 29 July 1999 (29.07.1999) US

Shell Internationale Research Maatschappij B.V.  
(71) Applicant (for all designated States except US): ENVEN-  
TURE GLOBAL TECHNOLOGY (US/US); 2135 High-  
way 6 South, Houston, TX 77077 (US);  
Carol Van Bylandtlaan 30, 2596 HR, The Hague (NL)

(72) Inventors; and

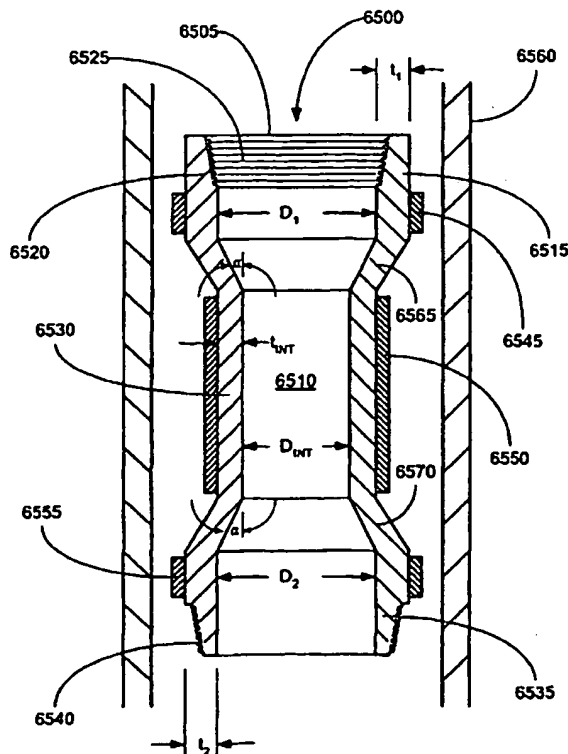
(75) Inventors/Applicants (for US only): COOK, Robert,

Lance [US/US]; 934 Caswell Court, Katy, TX 77450  
(US). BRISCO, David, P. [US/US]; 405 Westridge  
Drive, Duncan, OK 73533 (US). STEWART, R., Bruce  
[GB/NL]; Wassenaarseweg 208, NL-2596 EC The Hague  
(NL). WYANT, Reece, E. [US/US]; - (\*\*). RING,  
Lev [US/US]; 14126 Heatherhill Place, Houston, TX  
77077 (US). NAHM, James, Jang, Woo [-/US]; - (\*\*).  
HAUT, Richard, Carl [US/US]; 502 Lakebend Drive,  
Sugar Land, TX 77479-5831 (US). MACK, Robert,  
Donald [US/US]; 22435 Vobe Court, Katy, TX 77449  
(US). DUELL, Alan, B. [US/US]; 1408 Wisteria, Duncan,  
OK 73533 (US). FILIPPOV, Andrei, Gregory [US/US];  
2606 Hidden Shore Drive, Katy, TX 77450 (US).

2507 Round Meadow Court  
Fairport, NY 11731  
(74) Agents: MATTINGLY, Todd et al.; Haynes and Boone  
L.L.P., Suite 4300, 1000 Louisiana Street, Houston, TX  
77002-5012 (US).

(Continued on next page)

(54) Title: TWO-STEP RADIAL EXPANSION



(57) Abstract: A two-step radial expansion process. A first tubular member (6530) is radially expanded into contact with the interior surface of a second tubular member (6550). Both tubular members are then radially expanded.

WO 01/04535 A1

## TWO-STEP RADIAL EXPANSION

### Background of the Invention

5 This invention relates generally to expandable tubular members that may be expanded to form and/or repair wellbore casings, pipelines and structural supports such as foundation supports. The invention also extends to a method of forming such expandable tubular members and to wellbore casings and other apparatus that are formed or repaired using the expandable tubular members.

10 The invention will primarily be described with reference to wellbore casings, but it is to be understood that the expandable tubular members are not restricted to this use.

Conventionally, when a wellbore is created, a number of casings are installed in the borehole to prevent collapse of the borehole wall and to prevent undesired outflow of drilling fluid into the formation or inflow of fluid from the formation into the borehole.

15 The borehole is drilled in intervals whereby a casing which is to be installed in a lower borehole interval is lowered through a previously installed casing of an upper borehole interval. As a consequence of this procedure the casing of the lower interval is of smaller diameter than the casing of the upper interval. Thus, the casings are in a nested arrangement with casing diameters decreasing in downward direction. Cement annuli are  
 20 provided between the outer surfaces of the casings and the borehole wall to seal the casings from the borehole wall. As a consequence of this nested arrangement a relatively large borehole diameter is required at the upper part of the wellbore. Such a large borehole diameter involves increased costs due to heaving casing handling equipment, large drill bits and increased volumes of drilling fluid and drill cuttings. Moreover, increased drilling  
 25 rig time is involved due to required cement pumping, cement hardening, required equipment changes due to large variations in hole diameters drilled in the course of the well, and the large volume of cuttings drilled and removed.

Conventionally, at the surface end of the wellbore, a wellhead is formed that typically includes a surface casing, a number of production and/or drilling spools, valving,  
 30 and a Christmas tree. Typically the wellhead further includes a concentric arrangement of casings including a production casing and one or more intermediate casings. The casings

- 2 -

are typically supported using load bearing slips positioned above the ground. The conventional design and construction of wellheads is expensive and complex.

Conventionally, a wellbore casing cannot be formed during the drilling of a wellbore. Typically, the wellbore is drilled and then a wellbore casing is formed in the newly drilled section of the wellbore. This delays the completion of a well.

The present invention is particularly directed to overcoming one or more of the limitations of the existing procedures for forming wellbores and wellheads, but has broader applicability to expandable tubular members generally and to other apparatus formed by expansion of such members.

10

#### Summary of the Invention

According to the present invention, an expandable tubular member or use in forming and/or repairing a wellbore casing, pipeline or structural support is provided that includes a first tubular section having a first outer diameter and a first threaded connection, a second tubular section having a second outer diameter and a second threaded connection, and an intermediate tubular section between the first and second tubular sections and having an intermediate outer diameter, wherein the first and second outer diameters are greater than the intermediate outer diameter.

Also according to the present invention, a method of fabricating an expandable tubular member or use in forming and/or repairing a wellbore casing, pipeline or structural support is provided that includes providing a tubular member having a first end, a second end, and an intermediate portion; radially expanding the first end and the second end of the tubular member whereby the outer diameters of the first end and the second end are greater than the outer diameter of the intermediate portion; forming a first threaded connection on the first end of the tubular member; and forming a second threaded connection on the second end of the tubular member.

Further according to the present invention there is provided an expandable tubular member or use in forming and/or repairing a wellbore casing, pipeline or structural support when fabricated by a method as described in the immediately preceding paragraph.

Still further according to the present invention there is provided a wellbore casing,



- 3 -

pipeline or structural support comprising a tubular member formed by the process of radially expanding an expandable tubular member according to the present invention into contact with an approximately cylindrical passage using an expansion cone.

In the expandable tubular member, preferably the wall thicknesses of the first and  
5 second tubular sections are greater than the wall thickness of the intermediate tubular section.

The expandable tubular member conveniently further comprises a first tubular  
transitory portion between the first tubular section and the intermediate tubular section;  
and a second tubular transitory portion between the second tubular section and the  
10 intermediate tubular section; wherein the angles of inclination of the first and second  
tubular transitory portions relative to the intermediate tubular section are in the range of  
from about 0 to 30 degrees.

The outside diameter of the intermediate tubular section of the expandable tubular  
member is preferably in the range of from about 75 percent to about 98 percent of the  
15 outside diameters of the first and second tubular sections.

The burst strength of the first and second tubular sections of the expandable tubular  
member is advantageously substantially equal to that of the intermediate tubular section.

In a preferred embodiment of the expandable tubular member the first threaded  
connection comprises an internally threaded connection and the second threaded  
20 connection comprises an externally threaded connection

Preferably, in the expandable tubular member, the ratio of the inside diameters of  
the first and second tubular sections to the interior diameter of the intermediate tubular  
section is in the range of from about 100 to 120 percent.

In one preferred embodiment of the expandable tubular member the relationship  
25 between the wall thicknesses  $t_1$ ,  $t_2$  and  $t_{INT}$  of the first tubular section, the second tubular  
section, and the intermediate tubular section, respectively, of the tubular member, the  
inside diameters  $D_1$ ,  $D_2$  and  $D_{INT}$  of the first tubular section, the second tubular section,  
and the intermediate tubular section, respectively, of the tubular member, and the inside  
diameter  $D_{wellbore}$  of a wellbore casing that the tubular member will be inserted into, and  
30 the outside diameter  $D_{cone}$  of an expansion cone that will be used to radially expand the  
tubular member within the wellbore casing is given by the following expression:

- 4 -

$$D_{\text{wellbore}} - 2 * t_1 \geq D_1 \geq 1/t_1[(t_1 - t_{\text{INT}}) * D_{\text{conc}} + t_{\text{INT}} * D_{\text{INT}}];$$

wherein  $t_1 = t_2$ ; and wherein  $D_1 = D_2$ .

5            Preferably, the method of the invention includes one or more of the following additional steps: 1) upsetting the first and second ends of the tubular member; 2) stress relieving the radially expanded first and second ends of the tubular member; 3) applying a protective coating onto the radially expanded first and second ends of the tubular member; and 4) applying a coating of a sealant onto the intermediate portion of the tubular member.

10            The method of the invention conveniently further comprises forming a first tubular transitional portion between the first end and the intermediate portion of the tubular member; and forming a second tubular transitional portion between the second end and the intermediate portion of the tubular member; wherein the angles of inclination of the first and second tubular transitional portions relative to the intermediate portion are  
15 in the range of from about 0 to 30 degrees.

#### Brief Description of the Drawings

20            One embodiment of an expandable tubular member, a method and apparatus according to the invention in the field of wellbore casings, pipelines and structural supports, and associated methods and apparatus, will now be described by way of example only with reference to the accompanying drawings, in which:

- 5 -

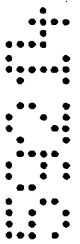
5

10

15

**THIS PAGE IS INTENTIONALLY LEFT BLANK**

20



25



30



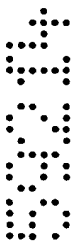
- 6 -

5

10

15

**THIS PAGE IS INTENTIONALLY LEFT BLANK**



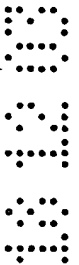
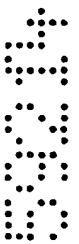
- 7 -

5

10

15

**THIS PAGE IS INTENTIONALLY LEFT BLANK**



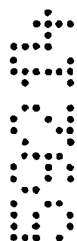
- 8 -

5

10

15

**THIS PAGE IS INTENTIONALLY LEFT BLANK**



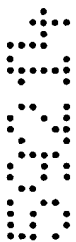
- 9 -

5

10

15

**THIS PAGE IS INTENTIONALLY LEFT BLANK**



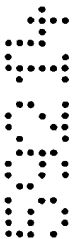
- 10 -

5

10

15

**THIS PAGE IS INTENTIONALLY LEFT BLANK**





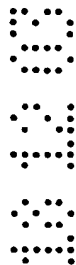
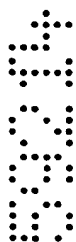
- 11 -

5

10

15

**THIS PAGE IS INTENTIONALLY LEFT BLANK**



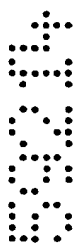
- 12 -

5

10

15

**THIS PAGE IS INTENTIONALLY LEFT BLANK**



- 13 -

5

10

15

**THIS PAGE IS INTENTIONALLY LEFT BLANK**



- 14 -

5

10

15

**THIS PAGE IS INTENTIONALLY LEFT BLANK**

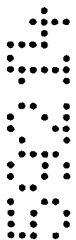


FIG. 1 is a fragmentary cross-sectional view illustrating the drilling of a new section of a well borehole.

FIG. 2 is a fragmentary cross-sectional view illustrating the placement of an  
5 embodiment of an apparatus for creating a casing within the new section of the well borehole.

FIG. 3 is a fragmentary cross-sectional view illustrating the injection of a first quantity of a fluidic material into the new section of the well borehole.

FIG. 3a is another fragmentary cross-sectional view illustrating the injection  
10 of a first quantity of a hardenable fluidic sealing material into the new section of the well borehole.

FIG. 4 is a fragmentary cross-sectional view illustrating the injection of a second quantity of a fluidic material into the new section of the well borehole.

FIG. 5 is a fragmentary cross-sectional view illustrating the drilling out of  
15 a portion of the cured hardenable fluidic sealing material from the new section of the well borehole.

FIG. 6 is a cross-sectional view of an embodiment of the overlapping joint between adjacent tubular members.

FIG. 7 is a fragmentary cross-sectional view of a preferred embodiment of  
20 the apparatus for creating a casing within a well borehole.

FIG. 8 is a fragmentary cross-sectional illustration of the placement of an expanded tubular member within another tubular member.

FIG. 9 is a cross-sectional illustration of a preferred embodiment of an apparatus for forming a casing including a drillable mandrel and shoe.

25 FIG. 9a is another cross-sectional illustration of the apparatus of FIG. 9.

FIG. 9b is another cross-sectional illustration of the apparatus of FIG. 9.

FIG. 9c is another cross-sectional illustration of the apparatus of FIG. 9.

FIG. 10a is a cross-sectional illustration of a wellbore including a pair of adjacent overlapping casings.

30 FIG. 10b is a cross-sectional illustration of an apparatus and method for creating a tie-back liner using an expandable tubular member.

FIG. 10c is a cross-sectional illustration of the pumping of a fluidic sealing material into the annular region between the tubular member and the existing casing.

FIG. 10d is a cross-sectional illustration of the pressurizing of the interior  
5 of the tubular member below the mandrel.

FIG. 10e is a cross-sectional illustration of the extrusion of the tubular member off of the mandrel.

FIG. 10f is a cross-sectional illustration of the tie-back liner before drilling out the shoe and packer.

10 FIG. 10g is a cross-sectional illustration of the completed tie-back liner created using an expandable tubular member.

FIG. 11a is a fragmentary cross-sectional view illustrating the drilling of a new section of a well borehole.

FIG. 11b is a fragmentary cross-sectional view illustrating the placement of  
15 an embodiment of an apparatus for hanging a tubular liner within the new section of the well borehole.

FIG. 11c is a fragmentary cross-sectional view illustrating the injection of a first quantity of a hardenable fluidic sealing material into the new section of the well borehole.

20 FIG. 11d is a fragmentary cross-sectional view illustrating the introduction of a wiper dart into the new section of the well borehole.

FIG. 11e is a fragmentary cross-sectional view illustrating the injection of a second quantity of a hardenable fluidic sealing material into the new section of the well borehole.

25 FIG. 11f is a fragmentary cross-sectional view illustrating the completion of the tubular liner.

FIG. 12 is a cross-sectional illustration of a preferred embodiment of a wellhead system utilizing expandable tubular members.

FIG. 13 is a partial cross-sectional illustration of a preferred embodiment  
30 of the wellhead system of FIG. 12.

FIG. 14a is an illustration of the formation of an embodiment of a mono-diameter wellbore casing.

WO 01/04535

PCT/US00/18635

FIG. 14b is another illustration of the formation of the mono-diameter wellbore casing.

FIG. 14c is another illustration of the formation of the mono-diameter wellbore casing.

5        FIG. 14d is another illustration of the formation of the mono-diameter wellbore casing.

FIG. 14e is another illustration of the formation of the mono-diameter wellbore casing.

10       FIG. 14f is another illustration of the formation of the mono-diameter wellbore casing.

FIG. 15 is an illustration of an embodiment of an apparatus for expanding a tubular member.

FIG. 15a is another illustration of the apparatus of FIG. 15.

FIG. 15b is another illustration of the apparatus of FIG. 15.

15       FIG. 16 is an illustration of an embodiment of an apparatus for forming a mono-diameter wellbore casing.

FIG. 17 is an illustration of an embodiment of an apparatus for expanding a tubular member.

FIG. 17a is another illustration of the apparatus of FIG. 16.

20       FIG. 17b is another illustration of the apparatus of FIG. 16.

FIG. 18 is an illustration of an embodiment of an apparatus for forming a mono-diameter wellbore casing.

FIG. 19 is an illustration of another embodiment of an apparatus for expanding a tubular member.

25       FIG. 19a is another illustration of the apparatus of FIG. 17.

FIG. 19b is another illustration of the apparatus of FIG. 17.

FIG. 20 is an illustration of an embodiment of an apparatus for forming a mono-diameter wellbore casing.

30       FIG. 21 is an illustration of the isolation of subterranean zones using expandable tubulars.

FIG. 22a is a fragmentary cross-sectional illustration of an embodiment of an apparatus for forming a wellbore casing while drilling a wellbore.

FIG. 22b is another fragmentary cross-sectional illustration of the apparatus of FIG. 22a.

FIG. 22c is another fragmentary cross-sectional illustration of the apparatus of FIG. 22a.

5        FIG. 22d is another fragmentary cross-sectional illustration of the apparatus of FIG. 22a.

FIG. 23a is a fragmentary cross-section illustration of an embodiment of an apparatus and method for expanding tubular members.

10       FIG. 23b is another fragmentary cross-sectional illustration of the apparatus of FIG. 23a.

FIG. 23c is another fragmentary cross-sectional illustration of the apparatus of FIG. 23a.

FIG. 24a is a fragmentary cross-section illustration of an embodiment of an apparatus and method for expanding tubular members.

15       FIG. 24b is another fragmentary cross-sectional illustration of the apparatus of FIG. 24a.

FIG. 24c is another fragmentary cross-sectional illustration of the apparatus of FIG. 24a.

20       FIG. 24d is another fragmentary cross-sectional illustration of the apparatus of FIG. 24a.

FIG. 24e is another fragmentary cross-sectional illustration of the apparatus of FIG. 24a.

FIG. 25 is a partial cross-sectional illustration of an expansion mandrel expanding a tubular member.

25       FIG. 26 is a graphical illustration of the relationship between propagation pressure and the angle of attack of the expansion mandrel.

FIG. 27 is a cross-sectional illustration of an embodiment of an expandable connector.

30       FIG. 28 is a cross-sectional illustration of another embodiment of an expandable connector.

FIG. 29 is a cross-sectional illustration of another embodiment of an expandable connector.



FIG. 30 is a cross-sectional illustration of another embodiment of an expandable connector.

FIG. 31 is a fragmentary cross-sectional illustration of the lubrication of the interface between an expansion mandrel and a tubular member during the radial  
5 expansion process.

FIG. 32 is an illustration of an embodiment of an expansion mandrel including a system for lubricating the interface between the expansion mandrel and a tubular member during the radial expansion of the tubular member.

FIG. 33 is an illustration of an embodiment of an expansion mandrel  
10 including a system for lubricating the interface between the expansion mandrel and a tubular member during the radial expansion of the tubular member.

FIG. 34 is an illustration of an embodiment of an expansion mandrel including a system for lubricating the interface between the expansion mandrel  
and a tubular member during the radial expansion of the tubular member.

FIG. 35 is an illustration of an embodiment of an expansion mandrel  
15 including a system for lubricating the interface between the expansion mandrel and a tubular member during the radial expansion of the tubular member.

FIG. 36 is an illustration of an embodiment of an expansion mandrel including a system for lubricating the interface between the expansion mandrel  
20 and a tubular member during the radial expansion of the tubular member.

FIG. 37 is an illustration of an embodiment of an expansion mandrel including a system for lubricating the interface between the expansion mandrel and a tubular member during the radial expansion of the tubular member.

FIG. 38 is an illustration of an embodiment of an expansion mandrel  
25 including a system for lubricating the interface between the expansion mandrel and a tubular member during the radial expansion of the tubular member.

FIG. 39 is an illustration of a preferred embodiment of an expansion mandrel including a system for lubricating the interface between the expansion mandrel and a tubular member during the radial expansion of the tubular  
30 member.

FIG. 40 is a cross-sectional illustration of the first axial groove of the expansion mandrel of FIG. 39.

FIG. 41 is a cross-sectional illustration of the circumferential groove of the expansion mandrel of FIG. 39.

FIG. 42 is a cross-sectional illustration of one of the second axial grooves of the expansion mandrel of FIG. 39.

5        FIG. 43 is a cross sectional illustration of an embodiment of an expansion mandrel including internal flow passages having inserts for adjusting the flow of lubricant fluids.

FIG. 44 is a cross sectional illustration of the expansion mandrel of FIG. 43 further including an insert having a filter for filtering out foreign materials from  
10 the lubricant fluids.

FIG. 45 is a cross sectional illustration of a preferred embodiment of an expandible tubular for use in forming and/or repairing a wellbore casing, pipeline, or foundation support.

FIG. 46 is a cross sectional illustration of the flared end of a tubular member  
15 selected for testing.

FIG. 47 is a cross sectional illustration of the flared end of a tubular member selected for testing that has structurally failed.

FIG. 48 is a cross sectional illustration of an embodiment of an expandable tubular member.

20        FIG. 49 is a flow chart illustration of an embodiment of a method for fabricating the expandable tubular member of FIG. 48.

FIG. 50a is a cross sectional illustration of a tubular member having upset end portions.

FIG. 50b is a cross sectional illustration of the tubular member of FIG. 50a  
25 after radial expansion of the upset end portions.

FIG. 50c is a cross sectional illustration of the tubular member of FIG. 50b further including expandable threaded connections provided in the expanded upset end portions.

FIG. 50d is a cross sectional illustration of tubular member of FIG. 50c,  
30 further including protective members provided on the outside diameter of the upset expanded portions of the tubular member.

FIG. 50e is a cross sectional illustration of the tubular member of FIG. 50d, further including a sealing member provided on the outside diameter of the intermediate unexpanded portion of the tubular member.

FIG. 51 is an illustration of an embodiment of an expansion cone optimally adapted to radially expand the tubular member of FIG. 48.

FIG. 52 is an illustration of another embodiment of an expansion cone optimally adapted to radially expand the tubular member of FIG. 48.

Fig. 53a is a fragmentary cross-sectional illustration of an embodiment of a wellbore casing formed using any one of the methods and apparatus for radially expanding a tubular member illustrated in Figs. 1-52.

Fig. 53b is a fragmentary cross-sectional illustration of an embodiment of a method and apparatus for further radially expanding the wellbore casing of Fig. 53a.

Fig. 53c. is a fragmentary cross-sectional illustration of the wellbore casing of Fig. 53b after further radial expansion.

#### Detailed Description of the Illustrative Embodiments

An apparatus and method for forming a wellbore casing within a subterranean formation is provided. The apparatus and method permits a wellbore casing to be formed in a subterranean formation by placing a tubular member and a mandrel in a new section of a wellbore, and then extruding the tubular member off of the mandrel by pressurizing an interior portion of the tubular member. The apparatus and method further permits adjacent tubular members in the wellbore to be joined using an overlapping joint that prevents fluid and or gas passage. The apparatus and method further permits a new tubular member to be supported by an existing tubular member by expanding the new tubular member into engagement with the existing tubular member. The apparatus and method further minimizes the reduction in the hole size of the wellbore casing necessitated by the addition of new sections of wellbore casing.

An apparatus and method for forming a tie-back liner using an expandable tubular member is also provided. The apparatus and method permits a tie-back liner to be created by extruding a tubular member off of a mandrel by pressurizing

and interior portion of the tubular member. In this manner, a tie-back liner is produced. The apparatus and method further permits adjacent tubular members in the wellbore to be joined using an overlapping joint that prevents fluid and/or gas passage. The apparatus and method further permits a new tubular member  
5 to be supported by an existing tubular member by expanding the new tubular member into engagement with the existing tubular member.

An apparatus and method for expanding a tubular member is also provided that includes an expandable tubular member, mandrel and a shoe. In a preferred embodiment, the interior portions of the apparatus is composed of materials that  
10 permit the interior portions to be removed using a conventional drilling apparatus. In this manner, in the event of a malfunction in a downhole region, the apparatus may be easily removed.

An apparatus and method for hanging an expandable tubular liner in a wellbore is also provided. The apparatus and method permit a tubular liner to be  
15 attached to an existing section of casing. The apparatus and method further have application to the joining of tubular members in general.

An apparatus and method for forming a wellhead system is also provided. The apparatus and method permit a wellhead to be formed including a number of expandable tubular members positioned in a concentric arrangement. The  
20 wellhead preferably includes an outer casing that supports a plurality of concentric casings using contact pressure between the inner casings and the outer casing. The resulting wellhead system eliminates many of the spools conventionally required, reduces the height of the Christmas tree facilitating servicing, lowers the load bearing areas of the wellhead resulting in a more stable system, and  
25 eliminates costly and expensive hanger systems.

An apparatus and method for forming a mono-diameter well casing is also provided. The apparatus and method permit the creation of a well casing in a wellbore having a substantially constant internal diameter. In this manner, the operation of an oil or gas well is greatly simplified.

30 An apparatus and method for expanding tubular members is also provided. The apparatus and method utilize a piston-cylinder configuration in which a pressurized chamber is used to drive a mandrel to radially expand tubular

members. In this manner, higher operating pressures can be utilized. Throughout the radial expansion process, the tubular member is never placed in direct contact with the operating pressures. In this manner, damage to the tubular member is prevented while also permitting controlled radial expansion of the tubular member

5 in a wellbore.

An apparatus and method for forming a mono-diameter wellbore casing is also provided. The apparatus and method utilize a piston-cylinder configuration in which a pressurized chamber is used to drive a mandrel to radially expand tubular members. In this manner, higher operating pressures can be utilized.

10 Throughout the radial expansion process, the tubular member is never placed in direct contact with the operating pressures. In this manner, damage to the tubular member is prevented while also permitting controlled radial expansion of the tubular member in a wellbore.

An apparatus and method for isolating one or more subterranean zones

15 from one or more other subterranean zones is also provided. The apparatus and method permits a producing zone to be isolated from a nonproducing zone using a combination of solid and slotted tubulars. In the production mode, the teachings of the present disclosure may be used in combination with conventional, well known, production completion equipment and methods using a series of packers,

20 solid tubing, perforated tubing, and sliding sleeves, which will be inserted into the disclosed apparatus to permit the commingling and/or isolation of the subterranean zones from each other.

An apparatus and method for forming a wellbore casing while the wellbore is drilled is also provided. In this manner, a wellbore casing can be formed

25 simultaneous with the drilling out of a new section of the wellbore. In a preferred embodiment, the apparatus and method is used in combination with one or more of the apparatus and methods disclosed in the present disclosure for forming wellbore casings using expandable tubulars. Alternatively, the method and apparatus can be used to create a pipeline or tunnel in a time efficient manner.

30 An expandable connector is also provided. In a preferred implementation, the expandable connector is used in conjunction with one or more of the disclosed embodiments for expanding tubular members. In this manner, the expansion of

a plurality of tubular members coupled to one another using the expandable connector is optimized.

A lubrication and self-cleaning system for an expansion cone is also provided. In a preferred implementation, the expansion cone includes one or more  
5 circumferential grooves and one or more axial grooves for providing a supply of lubricating fluid to the trailing edge portion of the interface between the expansion cone and a tubular member during the radial expansion process. In this manner, the frictional forces created during the radial expansion process are reduced which results in a reduction in the required operating pressures for radially expanding  
10 the tubular member. Furthermore, the supply of lubricating fluid preferably removes loose material from tapered end of the expansion cone that is formed during the radial expansion process.

A method of testing and selecting tubular members for radial expansion operations is also provided. In a preferred embodiment, the method provides  
15 tubular members that are optimally suited for radial expansion. In this manner, radially expanded tubular members having optimal structural properties are provided.

An expandable tubular member is provided that includes pre-expanded ends. In this manner, the subsequent radial expansion of the expandable tubular  
20 member is optimized.

An expansion cone for expanding a tubular member is also provided that include a first outer surface having a first angle of attack and a second outer surface having a second angle of attack less than the first angle of attack. In this manner, the expansion of tubular members is optimally provided.

25 A two-step process for coupling a first tubular member to a second tubular member is also provided. During the first stage of the process, the first tubular member is preferably radially expanded into contact with the interior surface of the second tubular member. During the second stage of the process, both tubular members are radially expanded. The resulting assembly preferably provides a  
30 substantially constant inside diameter.

In several alternative embodiments, the apparatus and methods are used to form and/or repair wellbore casings, pipelines, and/or structural supports.

Referring initially to Figs. 1-5, an embodiment of an apparatus and method for forming a wellbore casing within a subterranean formation will now be described. As illustrated in Fig. 1, a wellbore 100 is positioned in a subterranean formation 105. The wellbore 100 includes an existing cased section 110 having a tubular casing 115 and an annular outer layer of cement 120.

In order to extend the wellbore 100 into the subterranean formation 105, a drill string 125 is used in a well known manner to drill out material from the subterranean formation 105 to form a new section 130.

As illustrated in Fig. 2, an apparatus 200 for forming a wellbore casing in a subterranean formation is then positioned in the new section 130 of the wellbore 100. The apparatus 200 preferably includes an expandable mandrel or pig 205, a tubular member 210, a shoe 215, a lower cup seal 220, an upper cup seal 225, a fluid passage 230, a fluid passage 235, a fluid passage 240, seals 245, and a support member 250.

The expandable mandrel 205 is coupled to and supported by the support member 250. The expandable mandrel 205 is preferably adapted to controllably expand in a radial direction. The expandable mandrel 205 may comprise any number of conventional commercially available expandable mandrels modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the expandable mandrel 205 comprises a hydraulic expansion tool as disclosed in U.S. Patent No. 5,348,095, the contents of which are incorporated herein by reference, modified in accordance with the teachings of the present disclosure.

The tubular member 210 is supported by the expandable mandrel 205. The tubular member 210 is expanded in the radial direction and extruded off of the expandable mandrel 205. The tubular member 210 may be fabricated from any number of conventional commercially available materials such as, for example, Oilfield Country Tubular Goods (OCTG), 13 chromium steel tubing/casing, or plastic tubing/casing. In a preferred embodiment, the tubular member 210 is fabricated from OCTG in order to maximize strength after expansion. The inner and outer diameters of the tubular member 210 may range, for example, from approximately 0.75 to 47 inches and 1.05 to 48 inches, respectively. In a preferred

embodiment, the inner and outer diameters of the tubular member 210 range from about 3 to 15.5 inches and 3.5 to 16 inches, respectively in order to optimally provide minimal telescoping effect in the most commonly drilled wellbore sizes. The tubular member 210 preferably comprises a solid member.

5        In a preferred embodiment, the end portion 260 of the tubular member 210 is slotted, perforated, or otherwise modified to catch or slow down the mandrel 205 when it completes the extrusion of tubular member 210. In a preferred embodiment, the length of the tubular member 210 is limited to minimize the possibility of buckling. For typical tubular member 210 materials, the length of  
10   the tubular member 210 is preferably limited to between about 40 to 20,000 feet in length.

The shoe 215 is coupled to the expandable mandrel 205 and the tubular member 210. The shoe 215 includes fluid passage 240. The shoe 215 may comprise any number of conventional commercially available shoes such as, for  
15   example, Super Seal II float shoe, Super Seal II Down-Jet float shoe or a guide shoe with a sealing sleeve for a latch down plug modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the shoe 215 comprises an aluminum down-jet guide shoe with a sealing sleeve for a latch-down plug available from Halliburton Energy Services in Dallas, TX, modified in  
20   accordance with the teachings of the present disclosure, in order to optimally guide the tubular member 210 in the wellbore, optimally provide an adequate seal between the interior and exterior diameters of the overlapping joint between the tubular members, and to optimally allow the complete drill out of the shoe and plug after the completion of the cementing and expansion operations.

25        In a preferred embodiment, the shoe 215 includes one or more through and side outlet ports in fluidic communication with the fluid passage 240. In this manner, the shoe 215 optimally injects hardenable fluidic sealing material into the region outside the shoe 215 and tubular member 210. In a preferred embodiment, the shoe 215 includes the fluid passage 240 having an inlet geometry that can  
30   receive a dart and/or a ball sealing member. In this manner, the fluid passage 240 can be optimally sealed off by introducing a plug, dart and/or ball sealing elements into the fluid passage 230.



The lower cup seal 220 is coupled to and supported by the support member 250. The lower cup seal 220 prevents foreign materials from entering the interior region of the tubular member 210 adjacent to the expandable mandrel 205. The lower cup seal 220 may comprise any number of conventional commercially available cup seals such as, for example, TP cups, or Selective Injection Packer (SIP) cups modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the lower cup seal 220 comprises a SIP cup seal, available from Halliburton Energy Services in Dallas, TX in order to optimally block foreign material and contain a body of lubricant.

10 The upper cup seal 225 is coupled to and supported by the support member 250. The upper cup seal 225 prevents foreign materials from entering the interior region of the tubular member 210. The upper cup seal 225 may comprise any number of conventional commercially available cup seals such as, for example, TP cups or SIP cups modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the upper cup seal 225 comprises a SIP cup, available from Halliburton Energy Services in Dallas, TX in order to optimally block the entry of foreign materials and contain a body of lubricant.

The fluid passage 230 permits fluidic materials to be transported to and from the interior region of the tubular member 210 below the expandable mandrel 205. The fluid passage 230 is coupled to and positioned within the support member 250 and the expandable mandrel 205. The fluid passage 230 preferably extends from a position adjacent to the surface to the bottom of the expandable mandrel 205. The fluid passage 230 is preferably positioned along a centerline of the apparatus 200.

25 The fluid passage 230 is preferably selected, in the casing running mode of operation, to transport materials such as drilling mud or formation fluids at flow rates and pressures ranging from about 0 to 3,000 gallons/minute and 0 to 9,000 psi in order to minimize drag on the tubular member being run and to minimize surge pressures exerted on the wellbore which could cause a loss of wellbore fluids and lead to hole collapse.

The fluid passage 235 permits fluidic materials to be released from the fluid passage 230. In this manner, during placement of the apparatus 200 within the

new section 130 of the wellbore 100, fluidic materials 255 forced up the fluid passage 230 can be released into the wellbore 100 above the tubular member 210 thereby minimizing surge pressures on the wellbore section 130. The fluid passage 235 is coupled to and positioned within the support member 250. The fluid  
5 passage is further fluidically coupled to the fluid passage 230.

The fluid passage 235 preferably includes a control valve for controllably opening and closing the fluid passage 235. In a preferred embodiment, the control valve is pressure activated in order to controllably minimize surge pressures. The fluid passage 235 is preferably positioned substantially orthogonal to the centerline  
10 of the apparatus 200.

The fluid passage 235 is preferably selected to convey fluidic materials at flow rates and pressures ranging from about 0 to 3,000 gallons/minute and 0 to 9,000 psi in order to reduce the drag on the apparatus 200 during insertion into the new section 130 of the wellbore 100 and to minimize surge pressures on the  
15 new wellbore section 130.

The fluid passage 240 permits fluidic materials to be transported to and from the region exterior to the tubular member 210 and shoe 215. The fluid passage 240 is coupled to and positioned within the shoe 215 in fluidic communication with the interior region of the tubular member 210 below the  
20 expandable mandrel 205. The fluid passage 240 preferably has a cross-sectional shape that permits a plug, or other similar device, to be placed in fluid passage 240 to thereby block further passage of fluidic materials. In this manner, the interior region of the tubular member 210 below the expandable mandrel 205 can be fluidically isolated from the region exterior to the tubular member 210. This permits  
25 the interior region of the tubular member 210 below the expandable mandrel 205 to be pressurized. The fluid passage 240 is preferably positioned substantially along the centerline of the apparatus 200.

The fluid passage 240 is preferably selected to convey materials such as cement, drilling mud or epoxies at flow rates and pressures ranging from about 0  
30 to 3,000 gallons/minute and 0 to 9,000 psi in order to optimally fill the annular region between the tubular member 210 and the new section 130 of the wellbore 100 with fluidic materials. In a preferred embodiment, the fluid passage 240

includes an inlet geometry that can receive a dart and/or a ball sealing member. In this manner, the fluid passage 240 can be sealed off by introducing a plug, dart and/or ball sealing elements into the fluid passage 230.

The seals 245 are coupled to and supported by an end portion 260 of the tubular member 210. The seals 245 are further positioned on an outer surface 265 of the end portion 260 of the tubular member 210. The seals 245 permit the overlapping joint between the end portion 270 of the casing 115 and the portion 260 of the tubular member 210 to be fluidically sealed. The seals 245 may comprise any number of conventional commercially available seals such as, for example, lead, rubber, Teflon, or epoxy seals modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the seals 245 are molded from Stratalock epoxy available from Halliburton Energy Services in Dallas, TX in order to optimally provide a load bearing interference fit between the end 260 of the tubular member 210 and the end 270 of the existing casing 115.

In a preferred embodiment, the seals 245 are selected to optimally provide a sufficient frictional force to support the expanded tubular member 210 from the existing casing 115. In a preferred embodiment, the frictional force optimally provided by the seals 245 ranges from about 1,000 to 1,000,000 lbf in order to optimally support the expanded tubular member 210.

The support member 250 is coupled to the expandable mandrel 205, tubular member 210, shoe 215, and seals 220 and 225. The support member 250 preferably comprises an annular member having sufficient strength to carry the apparatus 200 into the new section 130 of the wellbore 100. In a preferred embodiment, the support member 250 further includes one or more conventional centralizers (not illustrated) to help stabilize the apparatus 200. In a preferred embodiment, the support member 250 comprises coiled tubing.

In a preferred embodiment, a quantity of lubricant 275 is provided in the annular region above the expandable mandrel 205 within the interior of the tubular member 210. In this manner, the extrusion of the tubular member 210 off of the expandable mandrel 205 is facilitated. The lubricant 275 may comprise any number of conventional commercially available lubricants such as, for example, Lubriplate, chlorine based lubricants, oil based lubricants or Climax 1500 Antisieze

WO 01/04535

PCT/US00/18635

(3100). In a preferred embodiment, the lubricant 275 comprises Climax 1500 Antisieze (3100) available from Climax Lubricants and Equipment Co. in Houston, TX in order to optimally provide optimum lubrication to facilitate the expansion process.

5 In a preferred embodiment, the support member 250 is thoroughly cleaned prior to assembly to the remaining portions of the apparatus 200. In this manner, the introduction of foreign material into the apparatus 200 is minimized. This minimizes the possibility of foreign material clogging the various flow passages and valves of the apparatus 200.

10 In a preferred embodiment, before or after positioning the apparatus 200 within the new section 130 of the wellbore 100, a couple of wellbore volumes are circulated in order to ensure that no foreign materials are located within the wellbore 100 that might clog up the various flow passages and valves of the apparatus 200 and to ensure that no foreign material interferes with the expansion  
15 process.

As illustrated in Fig. 3, the fluid passage 235 is then closed and a hardenable fluidic sealing material 305 is then pumped from a surface location into the fluid passage 230. The material 305 then passes from the fluid passage 230 into the interior region 310 of the tubular member 210 below the expandable mandrel 205.

20 The material 305 then passes from the interior region 310 into the fluid passage 240. The material 305 then exits the apparatus 200 and fills the annular region 315 between the exterior of the tubular member 210 and the interior wall of the new section 130 of the wellbore 100. Continued pumping of the material 305 causes the material 305 to fill up at least a portion of the annular region 315.

25 The material 305 is preferably pumped into the annular region 315 at pressures and flow rates ranging, for example, from about 0 to 5000 psi and 0 to 1,500 gallons/min, respectively. The optimum flow rate and operating pressures vary as a function of the casing and wellbore sizes, wellbore section length, available pumping equipment, and fluid properties of the fluidic material being  
30 pumped. The optimum flow rate and operating pressure are preferably determined using conventional empirical methods.

The hardenable fluidic sealing material 305 may comprise any number of conventional commercially available hardenable fluidic sealing materials such as, for example, slag mix, cement or epoxy. In a preferred embodiment, the hardenable fluidic sealing material 305 comprises a blended cement prepared specifically for the particular well section being drilled from Halliburton Energy Services in Dallas, TX in order to provide optimal support for tubular member 210 while also maintaining optimum flow characteristics so as to minimize difficulties during the displacement of cement in the annular region 315. The optimum blend of the blended cement is preferably determined using conventional empirical methods.

The annular region 315 preferably is filled with the material 305 in sufficient quantities to ensure that, upon radial expansion of the tubular member 210, the annular region 315 of the new section 130 of the wellbore 100 will be filled with material 305.

In a particularly preferred embodiment, as illustrated in Fig. 3a, the wall thickness and/or the outer diameter of the tubular member 210 is reduced in the region adjacent to the mandrel 205 in order optimally permit placement of the apparatus 200 in positions in the wellbore with tight clearances. Furthermore, in this manner, the initiation of the radial expansion of the tubular member 210 during the extrusion process is optimally facilitated.

As illustrated in Fig. 4, once the annular region 315 has been adequately filled with material 305, a plug 405, or other similar device, is introduced into the fluid passage 240 thereby fluidically isolating the interior region 310 from the annular region 315. In a preferred embodiment, a non-hardenable fluidic material 306 is then pumped into the interior region 310 causing the interior region to pressurize. In this manner, the interior of the expanded tubular member 210 will not contain significant amounts of cured material 305. This reduces and simplifies the cost of the entire process. Alternatively, the material 305 may be used during this phase of the process. Once the interior region 310 becomes sufficiently pressurized, the tubular member 210 is extruded off of the expandable mandrel 205. During the extrusion process, the expandable mandrel 205 may be raised out of the expanded portion of the tubular member 210. In a preferred embodiment,

during the extrusion process, the mandrel 205 is raised at approximately the same rate as the tubular member 210 is expanded in order to keep the tubular member 210 stationary relative to the new wellbore section 130. In an alternative preferred embodiment, the extrusion process is commenced with the tubular member 210  
5 positioned above the bottom of the new wellbore section 130, keeping the mandrel 205 stationary, and allowing the tubular member 210 to extrude off of the mandrel 205 and fall down the new wellbore section 130 under the force of gravity.

The plug 405 is preferably placed into the fluid passage 240 by introducing the plug 405 into the fluid passage 230 at a surface location in a conventional  
10 manner. The plug 405 preferably acts to fluidically isolate the hardenable fluidic sealing material 305 from the non hardenable fluidic material 306.

The plug 405 may comprise any number of conventional commercially available devices from plugging a fluid passage such as, for example, Multiple Stage  
Cementer (MSC) latch-down plug, Omega latch-down plug or three-wiper latch-  
15 down plug modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the plug 405 comprises a MSC latch-down plug available from Halliburton Energy Services in Dallas, TX.

After placement of the plug 405 in the fluid passage 240, a non hardenable fluidic material 306 is preferably pumped into the interior region 310 at pressures  
20 and flow rates ranging, for example, from approximately 400 to 10,000 psi and 30 to 4,000 gallons/min. In this manner, the amount of hardenable fluidic sealing material within the interior 310 of the tubular member 210 is minimized. In a preferred embodiment, after placement of the plug 405 in the fluid passage 240, the non hardenable material 306 is preferably pumped into the interior region 310  
25 at pressures and flow rates ranging from approximately 500 to 9,000 psi and 40 to 3,000 gallons/min in order to maximize the extrusion speed.

In a preferred embodiment, the apparatus 200 is adapted to minimize tensile, burst, and friction effects upon the tubular member 210 during the expansion process. These effects will depend upon the geometry of the expansion  
30 mandrel 205, the material composition of the tubular member 210 and expansion mandrel 205, the inner diameter of the tubular member 210, the wall thickness of the tubular member 210, the type of lubricant, and the yield strength of the

tubular member 210. In general, the thicker the wall thickness, the smaller the inner diameter, and the greater the yield strength of the tubular member 210, then the greater the operating pressures required to extrude the tubular member 210 off of the mandrel 205.

- 5        For typical tubular members 210, the extrusion of the tubular member 210 off of the expandable mandrel will begin when the pressure of the interior region 310 reaches, for example, approximately 500 to 9,000 psi.

- 10        During the extrusion process, the expandable mandrel 205 may be raised out of the expanded portion of the tubular member 210 at rates ranging, for example, from about 0 to 5 ft/sec. In a preferred embodiment, during the extrusion process, the expandable mandrel 205 is raised out of the expanded portion of the tubular member 210 at rates ranging from about 0 to 2 ft/sec in order to minimize the time required for the expansion process while also permitting easy control of the expansion process.

- 15        When the end portion 260 of the tubular member 210 is extruded off of the expandable mandrel 205, the outer surface 265 of the end portion 260 of the tubular member 210 will preferably contact the interior surface 410 of the end portion 270 of the casing 115 to form an fluid tight overlapping joint. The contact pressure of the overlapping joint may range, for example, from approximately 50  
20        to 20,000 psi. In a preferred embodiment, the contact pressure of the overlapping joint ranges from approximately 400 to 10,000 psi in order to provide optimum pressure to activate the annular sealing members 245 and optimally provide resistance to axial motion to accommodate typical tensile and compressive loads.

- 25        The overlapping joint between the section 410 of the existing casing 115 and the section 265 of the expanded tubular member 210 preferably provides a gaseous and fluidic seal. In a particularly preferred embodiment, the sealing members 245 optimally provide a fluidic and gaseous seal in the overlapping joint.

- 30        In a preferred embodiment, the operating pressure and flow rate of the non hardenable fluidic material 306 is controllably ramped down when the expandable mandrel 205 reaches the end portion 260 of the tubular member 210. In this manner, the sudden release of pressure caused by the complete extrusion of the

tubular member 210 off of the expandable mandrel 205 can be minimized. In a preferred embodiment, the operating pressure is reduced in a substantially linear fashion from 100% to about 10% during the end of the extrusion process beginning when the mandrel 205 is within about 5 feet from completion of the extrusion process.

Alternatively, or in combination, a shock absorber is provided in the support member 250 in order to absorb the shock caused by the sudden release of pressure. The shock absorber may comprise, for example, any conventional commercially available shock absorber adapted for use in wellbore operations.

Alternatively, or in combination, a mandrel catching structure is provided in the end portion 260 of the tubular member 210 in order to catch or at least decelerate the mandrel 205.

Once the extrusion process is completed, the expandable mandrel 205 is removed from the wellbore 100. In a preferred embodiment, either before or after the removal of the expandable mandrel 205, the integrity of the fluidic seal of the overlapping joint between the upper portion 260 of the tubular member 210 and the lower portion 270 of the casing 115 is tested using conventional methods.

If the fluidic seal of the overlapping joint between the upper portion 260 of the tubular member 210 and the lower portion 270 of the casing 115 is satisfactory, then any uncured portion of the material 305 within the expanded tubular member 210 is then removed in a conventional manner such as, for example, circulating the uncured material out of the interior of the expanded tubular member 210. The mandrel 205 is then pulled out of the wellbore section 130 and a drill bit or mill is used in combination with a conventional drilling assembly 505 to drill out any hardened material 305 within the tubular member 210. The material 305 within the annular region 315 is then allowed to cure.

As illustrated in Fig. 5, preferably any remaining cured material 305 within the interior of the expanded tubular member 210 is then removed in a conventional manner using a conventional drill string 505. The resulting new section of casing 510 includes the expanded tubular member 210 and an outer annular layer 515 of cured material 305. The bottom portion of the apparatus 200



comprising the shoe 215 and dart 405 may then be removed by drilling out the shoe 215 and dart 405 using conventional drilling methods.

In a preferred embodiment, as illustrated in Fig. 6, the upper portion 260 of the tubular member 210 includes one or more sealing members 605 and one or  
5 more pressure relief holes 610. In this manner, the overlapping joint between the lower portion 270 of the casing 115 and the upper portion 260 of the tubular member 210 is pressure-tight and the pressure on the interior and exterior surfaces of the tubular member 210 is equalized during the extrusion process.

In a preferred embodiment, the sealing members 605 are seated within  
10 recesses 615 formed in the outer surface 265 of the upper portion 260 of the tubular member 210. In an alternative preferred embodiment, the sealing members 605 are bonded or molded onto the outer surface 265 of the upper portion 260 of the tubular member 210. The pressure relief holes 610 are preferably  
15 positioned in the last few feet of the tubular member 210. The pressure relief holes reduce the operating pressures required to expand the upper portion 260 of the tubular member 210. This reduction in required operating pressure in turn reduces the velocity of the mandrel 205 upon the completion of the extrusion process. This reduction in velocity in turn minimizes the mechanical shock to the  
entire apparatus 200 upon the completion of the extrusion process.

Referring now to Fig. 7, a particularly preferred embodiment of an  
20 apparatus 700 for forming a casing within a wellbore preferably includes an expandable mandrel or pig 705, an expandable mandrel or pig container 710, a tubular member 715, a float shoe 720, a lower cup seal 725, an upper cup seal 730, a fluid passage 735, a fluid passage 740, a support member 745, a body of lubricant  
25 750, an overshot connection 755, another support member 760, and a stabilizer 765.

The expandable mandrel 705 is coupled to and supported by the support member 745. The expandable mandrel 705 is further coupled to the expandable mandrel container 710. The expandable mandrel 705 is preferably adapted to  
30 controllably expand in a radial direction. The expandable mandrel 705 may comprise any number of conventional commercially available expandable mandrels modified in accordance with the teachings of the present disclosure. In a preferred

embodiment, the expandable mandrel 705 comprises a hydraulic expansion tool substantially as disclosed in U.S. Pat. No. 5,348,095, the contents of which are incorporated herein by reference, modified in accordance with the teachings of the present disclosure.

5       The expandable mandrel container 710 is coupled to and supported by the support member 745. The expandable mandrel container 710 is further coupled to the expandable mandrel 705. The expandable mandrel container 710 may be constructed from any number of conventional commercially available materials such as, for example, Oilfield Country Tubular Goods, stainless steel, titanium or  
10   high strength steels. In a preferred embodiment, the expandable mandrel container 710 is fabricated from material having a greater strength than the material from which the tubular member 715 is fabricated. In this manner, the container 710 can be fabricated from a tubular material having a thinner wall thickness than the tubular member 210. This permits the container 710 to pass  
15   through tight clearances thereby facilitating its placement within the wellbore.

In a preferred embodiment, once the expansion process begins, and the thicker, lower strength material of the tubular member 715 is expanded, the outside diameter of the tubular member 715 is greater than the outside diameter of the container 710.

20       The tubular member 715 is coupled to and supported by the expandable mandrel 705. The tubular member 715 is preferably expanded in the radial direction and extruded off of the expandable mandrel 705 substantially as described above with reference to Figs. 1-6. The tubular member 715 may be fabricated from any number of materials such as, for example, Oilfield Country  
25   Tubular Goods (OCTG), automotive grade steel or plastics. In a preferred embodiment, the tubular member 715 is fabricated from OCTG.

In a preferred embodiment, the tubular member 715 has a substantially annular cross-section. In a particularly preferred embodiment, the tubular member 715 has a substantially circular annular cross-section.

30       The tubular member 715 preferably includes an upper section 805, an intermediate section 810, and a lower section 815. The upper section 805 of the tubular member 715 preferably is defined by the region beginning in the vicinity

of the mandrel container 710 and ending with the top section 820 of the tubular member 715. The intermediate section 810 of the tubular member 715 is preferably defined by the region beginning in the vicinity of the top of the mandrel container 710 and ending with the region in the vicinity of the mandrel 705. The lower section of the tubular member 715 is preferably defined by the region beginning in the vicinity of the mandrel 705 and ending at the bottom 825 of the tubular member 715.

In a preferred embodiment, the wall thickness of the upper section 805 of the tubular member 715 is greater than the wall thicknesses of the intermediate and lower sections 810 and 815 of the tubular member 715 in order to optimally facilitate the initiation of the extrusion process and optimally permit the apparatus 700 to be positioned in locations in the wellbore having tight clearances.

The outer diameter and wall thickness of the upper section 805 of the tubular member 715 may range, for example, from about 1.05 to 48 inches and 1/8 to 2 inches, respectively. In a preferred embodiment, the outer diameter and wall thickness of the upper section 805 of the tubular member 715 range from about 3.5 to 16 inches and 3/8 to 1.5 inches, respectively.

The outer diameter and wall thickness of the intermediate section 810 of the tubular member 715 may range, for example, from about 2.5 to 50 inches and 1/16 to 1.5 inches, respectively. In a preferred embodiment, the outer diameter and wall thickness of the intermediate section 810 of the tubular member 715 range from about 3.5 to 19 inches and 1/8 to 1.25 inches, respectively.

The outer diameter and wall thickness of the lower section 815 of the tubular member 715 may range, for example, from about 2.5 to 50 inches and 1/16 to 1.25 inches, respectively. In a preferred embodiment, the outer diameter and wall thickness of the lower section 810 of the tubular member 715 range from about 3.5 to 19 inches and 1/8 to 1.25 inches, respectively. In a particularly preferred embodiment, the wall thickness of the lower section 815 of the tubular member 715 is further increased to increase the strength of the shoe 720 when drillable materials such as, for example, aluminum are used.

The tubular member 715 preferably comprises a solid tubular member. In a preferred embodiment, the end portion 820 of the tubular member 715 is slotted,

perforated, or otherwise modified to catch or slow down the mandrel 705 when it completes the extrusion of tubular member 715. In a preferred embodiment, the length of the tubular member 715 is limited to minimize the possibility of buckling. For typical tubular member 715 materials, the length of the tubular member 715 is preferably limited to between about 40 to 20,000 feet in length.

The shoe 720 is coupled to the expandable mandrel 705 and the tubular member 715. The shoe 720 includes the fluid passage 740. In a preferred embodiment, the shoe 720 further includes an inlet passage 830, and one or more jet ports 835. In a particularly preferred embodiment, the cross-sectional shape of the inlet passage 830 is adapted to receive a latch-down dart, or other similar elements, for blocking the inlet passage 830. The interior of the shoe 720 preferably includes a body of solid material 840 for increasing the strength of the shoe 720. In a particularly preferred embodiment, the body of solid material 840 comprises aluminum.

The shoe 720 may comprise any number of conventional commercially available shoes such as, for example, Super Seal II Down-Jet float shoe, or guide shoe with a sealing sleeve for a latch down plug modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the shoe 720 comprises an aluminum down-jet guide shoe with a sealing sleeve for a latch-down plug available from Halliburton Energy Services in Dallas, TX, modified in accordance with the teachings of the present disclosure, in order to optimize guiding the tubular member 715 in the wellbore, optimize the seal between the tubular member 715 and an existing wellbore casing, and to optimally facilitate the removal of the shoe 720 by drilling it out after completion of the extrusion process.

The lower cup seal 725 is coupled to and supported by the support member 745. The lower cup seal 725 prevents foreign materials from entering the interior region of the tubular member 715 above the expandable mandrel 705. The lower cup seal 725 may comprise any number of conventional commercially available cup seals such as, for example, TP cups or Selective Injection Packer (SIP) cups modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the lower cup seal 725 comprises a SIP cup, available from

Halliburton Energy Services in Dallas, TX in order to optimally provide a debris barrier and hold a body of lubricant.

The upper cup seal 730 is coupled to and supported by the support member 760. The upper cup seal 730 prevents foreign materials from entering the interior  
5 region of the tubular member 715. The upper cup seal 730 may comprise any number of conventional commercially available cup seals such as, for example, TP cups or Selective Injection Packer (SIP) cup modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the upper cup seal 730 comprises a SIP cup available from Halliburton Energy Services in Dallas, TX  
10 in order to optimally provide a debris barrier and contain a body of lubricant.

The fluid passage 735 permits fluidic materials to be transported to and from the interior region of the tubular member 715 below the expandable mandrel 705. The fluid passage 735 is fluidically coupled to the fluid passage 740. The fluid  
15 passage 735 is preferably coupled to and positioned within the support member 760, the support member 745, the mandrel container 710, and the expandable mandrel 705. The fluid passage 735 preferably extends from a position adjacent to the surface to the bottom of the expandable mandrel 705. The fluid passage 735 is preferably positioned along a centerline of the apparatus 700. The fluid passage 735 is preferably selected to transport materials such as cement, drilling mud or  
20 epoxies at flow rates and pressures ranging from about 40 to 3,000 gallons/minute and 500 to 9,000 psi in order to optimally provide sufficient operating pressures to extrude the tubular member 715 off of the expandable mandrel 705.

As described above with reference to Figs. 1-6, during placement of the apparatus 700 within a new section of a wellbore, fluidic materials forced up the  
25 fluid passage 735 can be released into the wellbore above the tubular member 715. In a preferred embodiment, the apparatus 700 further includes a pressure release passage that is coupled to and positioned within the support member 260. The pressure release passage is further fluidically coupled to the fluid passage 735. The pressure release passage preferably includes a control valve for controllably  
30 opening and closing the fluid passage. In a preferred embodiment, the control valve is pressure activated in order to controllably minimize surge pressures. The pressure release passage is preferably positioned substantially orthogonal to the

centerline of the apparatus 700. The pressure release passage is preferably selected to convey materials such as cement, drilling mud or epoxies at flow rates and pressures ranging from about 0 to 500 gallons/minute and 0 to 1,000 psi in order to reduce the drag on the apparatus 700 during insertion into a new section  
5 of a wellbore and to minimize surge pressures on the new wellbore section.

The fluid passage 740 permits fluidic materials to be transported to and from the region exterior to the tubular member 715. The fluid passage 740 is preferably coupled to and positioned within the shoe 720 in fluidic communication with the interior region of the tubular member 715 below the expandable mandrel  
10 705. The fluid passage 740 preferably has a cross-sectional shape that permits a plug, or other similar device, to be placed in the inlet 830 of the fluid passage 740 to thereby block further passage of fluidic materials. In this manner, the interior region of the tubular member 715 below the expandable mandrel 705 can be optimally fluidically isolated from the region exterior to the tubular member 715.  
15 This permits the interior region of the tubular member 715 below the expandable mandrel 205 to be pressurized.

The fluid passage 740 is preferably positioned substantially along the centerline of the apparatus 700. The fluid passage 740 is preferably selected to convey materials such as cement, drilling mud or epoxies at flow rates and  
20 pressures ranging from about 0 to 3,000 gallons/minute and 0 to 9,000 psi in order to optimally fill an annular region between the tubular member 715 and a new section of a wellbore with fluidic materials. In a preferred embodiment, the fluid passage 740 includes an inlet passage 830 having a geometry that can receive a dart and/or a ball sealing member. In this manner, the fluid passage 240 can be  
25 sealed off by introducing a plug, dart and/or ball sealing elements into the fluid passage 230.

In a preferred embodiment, the apparatus 700 further includes one or more seals 845 coupled to and supported by the end portion 820 of the tubular member 715. The seals 845 are further positioned on an outer surface of the end portion  
30 820 of the tubular member 715. The seals 845 permit the overlapping joint between an end portion of preexisting casing and the end portion 820 of the tubular member 715 to be fluidically sealed. The seals 845 may comprise any

WO 01/04535

PCT/US00/18635

number of conventional commercially available seals such as, for example, lead, rubber, Teflon, or epoxy seals modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the seals 845 comprise seals molded from StrataLock epoxy available from Halliburton Energy Services in  
5 Dallas, TX in order to optimally provide a hydraulic seal and a load bearing interference fit in the overlapping joint between the tubular member 715 and an existing casing with optimal load bearing capacity to support the tubular member 715.

In a preferred embodiment, the seals 845 are selected to provide a sufficient  
10 frictional force to support the expanded tubular member 715 from the existing casing. In a preferred embodiment, the frictional force provided by the seals 845 ranges from about 1,000 to 1,000,000 lbf in order to optimally support the expanded tubular member 715.

The support member 745 is preferably coupled to the expandable mandrel  
15 705 and the overshot connection 755. The support member 745 preferably comprises an annular member having sufficient strength to carry the apparatus 700 into a new section of a wellbore. The support member 745 may comprise any number of conventional commercially available support members such as, for example, steel drill pipe, coiled tubing or other high strength tubular modified in  
20 accordance with the teachings of the present disclosure. In a preferred embodiment, the support member 745 comprises conventional drill pipe available from various steel mills in the United States.

In a preferred embodiment, a body of lubricant 750 is provided in the annular region above the expandable mandrel container 710 within the interior of  
25 the tubular member 715. In this manner, the extrusion of the tubular member 715 off of the expandable mandrel 705 is facilitated. The lubricant 705 may comprise any number of conventional commercially available lubricants such as, for example, Lubriplate, chlorine based lubricants, oil based lubricants, or Climax 1500 Antisieze (3100). In a preferred embodiment, the lubricant 750 comprises  
30 Climax 1500 Antisieze (3100) available from Halliburton Energy Services in Houston, TX in order to optimally provide lubrication to facilitate the extrusion process.

The overshot connection 755 is coupled to the support member 745 and the support member 760. The overshot connection 755 preferably permits the support member 745 to be removably coupled to the support member 760. The overshot connection 755 may comprise any number of conventional commercially available  
5 overshot connections such as, for example, Innerstring Sealing Adapter, Innerstring Flat-Face Sealing Adapter or EZ Drill Setting Tool Stinger. In a preferred embodiment, the overshot connection 755 comprises a Innerstring Adapter with an Upper Guide available from Halliburton Energy Services in Dallas, TX.

10 The support member 760 is preferably coupled to the overshot connection 755 and a surface support structure (not illustrated). The support member 760 preferably comprises an annular member having sufficient strength to carry the apparatus 700 into a new section of a wellbore. The support member 760 may  
15 comprise any number of conventional commercially available support members such as, for example, steel drill pipe, coiled tubing or other high strength tubulars modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the support member 760 comprises a conventional drill pipe available from steel mills in the United States.

The stabilizer 765 is preferably coupled to the support member 760. The  
20 stabilizer 765 also preferably stabilizes the components of the apparatus 700 within the tubular member 715. The stabilizer 765 preferably comprises a spherical member having an outside diameter that is about 80 to 99% of the interior diameter of the tubular member 715 in order to optimally minimize buckling of the tubular member 715. The stabilizer 765 may comprise any number  
25 of conventional commercially available stabilizers such as, for example, EZ Drill Star Guides, packer shoes or drag blocks modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the stabilizer 765 comprises a sealing adapter upper guide available from Halliburton Energy Services in Dallas, TX.

30 In a preferred embodiment, the support members 745 and 760 are thoroughly cleaned prior to assembly to the remaining portions of the apparatus 700. In this manner, the introduction of foreign material into the apparatus 700



is minimized. This minimizes the possibility of foreign material clogging the various flow passages and valves of the apparatus 700.

In a preferred embodiment, before or after positioning the apparatus 700 within a new section of a wellbore, a couple of wellbore volumes are circulated  
5 through the various flow passages of the apparatus 700 in order to ensure that no foreign materials are located within the wellbore that might clog up the various flow passages and valves of the apparatus 700 and to ensure that no foreign material interferes with the expansion mandrel 705 during the expansion process.

In a preferred embodiment, the apparatus 700 is operated substantially as  
10 described above with reference to Figs. 1-7 to form a new section of casing within a wellbore.

As illustrated in Fig. 8, in an alternative preferred embodiment, the method and apparatus described herein is used to repair an existing wellbore casing 805  
by forming a tubular liner 810 inside of the existing wellbore casing 805. In a  
15 preferred embodiment, an outer annular lining of cement is not provided in the repaired section. In the alternative preferred embodiment, any number of fluidic materials can be used to expand the tubular liner 810 into intimate contact with the damaged section of the wellbore casing such as, for example, cement, epoxy, slag mix, or drilling mud. In the alternative preferred embodiment, sealing  
20 members 815 are preferably provided at both ends of the tubular member in order to optimally provide a fluidic seal. In an alternative preferred embodiment, the tubular liner 810 is formed within a horizontally positioned pipeline section, such as those used to transport hydrocarbons or water, with the tubular liner 810 placed in an overlapping relationship with the adjacent pipeline section. In this manner,  
25 underground pipelines can be repaired without having to dig out and replace the damaged sections.

In another alternative preferred embodiment, the method and apparatus described herein is used to directly line a wellbore with a tubular liner 810. In a preferred embodiment, an outer annular lining of cement is not provided between  
30 the tubular liner 810 and the wellbore. In the alternative preferred embodiment, any number of fluidic materials can be used to expand the tubular liner 810 into

intimate contact with the wellbore such as, for example, cement, epoxy, slag mix, or drilling mud.

Referring now to Figs. 9, 9a, 9b and 9c, a preferred embodiment of an apparatus 900 for forming a wellbore casing includes an expandable tubular member 902, a support member 904, an expandable mandrel or pig 906, and a shoe 908. In a preferred embodiment, the design and construction of the mandrel 906 and shoe 908 permits easy removal of those elements by drilling them out. In this manner, the assembly 900 can be easily removed from a wellbore using a conventional drilling apparatus and corresponding drilling methods.

The expandable tubular member 902 preferably includes an upper portion 910, an intermediate portion 912 and a lower portion 914. During operation of the apparatus 900, the tubular member 902 is preferably extruded off of the mandrel 906 by pressurizing an interior region 966 of the tubular member 902. The tubular member 902 preferably has a substantially annular cross-section.

In a particularly preferred embodiment, an expandable tubular member 915 is coupled to the upper portion 910 of the expandable tubular member 902. During operation of the apparatus 900, the tubular member 915 is preferably extruded off of the mandrel 906 by pressurizing the interior region 966 of the tubular member 902. The tubular member 915 preferably has a substantially annular cross-section.

In a preferred embodiment, the wall thickness of the tubular member 915 is greater than the wall thickness of the tubular member 902.

The tubular member 915 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield tubulars, low alloy steels, titanium or stainless steels. In a preferred embodiment, the tubular member 915 is fabricated from oilfield tubulars in order to optimally provide approximately the same mechanical properties as the tubular member 902. In a particularly preferred embodiment, the tubular member 915 has a plastic yield point ranging from about 40,000 to 135,000 psi in order to optimally provide approximately the same yield properties as the tubular member 902. The tubular member 915 may comprise a plurality of tubular members coupled end to end.

WO 01/04535

PCT/US00/18635

In a preferred embodiment, the upper end portion of the tubular member 915 includes one or more sealing members for optimally providing a fluidic and/or gaseous seal with an existing section of wellbore casing.

In a preferred embodiment, the combined length of the tubular members 5 902 and 915 are limited to minimize the possibility of buckling. For typical tubular member materials, the combined length of the tubular members 902 and 915 are limited to between about 40 to 20,000 feet in length.

The lower portion 914 of the tubular member 902 is preferably coupled to the shoe 908 by a threaded connection 968. The intermediate portion 912 of the 10 tubular member 902 preferably is placed in intimate sliding contact with the mandrel 906.

The tubular member 902 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield tubulars, low alloy steels, titanium or stainless steels. In a preferred embodiment, 15 the tubular member 902 is fabricated from oilfield tubulars in order to optimally provide approximately the same mechanical properties as the tubular member 915. In a particularly preferred embodiment, the tubular member 902 has a plastic yield point ranging from about 40,000 to 135,000 psi in order to optimally provide approximately the same yield properties as the tubular member 915.

20 The wall thickness of the upper, intermediate, and lower portions, 910, 912 and 914 of the tubular member 902 may range, for example, from about 1/16 to 1.5 inches. In a preferred embodiment, the wall thickness of the upper, intermediate, and lower portions, 910, 912 and 914 of the tubular member 902 range from about 1/8 to 1.25 in order to optimally provide wall thickness that are about the same as 25 the tubular member 915. In a preferred embodiment, the wall thickness of the lower portion 914 is less than or equal to the wall thickness of the upper portion 910 in order to optimally provide a geometry that will fit into tight clearances downhole.

The outer diameter of the upper, intermediate, and lower portions, 910, 912 30 and 914 of the tubular member 902 may range, for example, from about 1.05 to 48 inches. In a preferred embodiment, the outer diameter of the upper, intermediate, and lower portions, 910, 912 and 914 of the tubular member 902 range from about

3 ½ to 19 inches in order to optimally provide the ability to expand the most commonly used oilfield tubulars.

The length of the tubular member 902 is preferably limited to between about 2 to 5 feet in order to optimally provide enough length to contain the  
5 mandrel 906 and a body of lubricant.

The tubular member 902 may comprise any number of conventional commercially available tubular members modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the tubular member 902 comprises Oilfield Country Tubular Goods available from various U.S. steel mills.  
10 The tubular member 915 may comprise any number of conventional commercially available tubular members modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the tubular member 915 comprises Oilfield Country Tubular Goods available from various U.S. steel mills.

The various elements of the tubular member 902 may be coupled using any  
15 number of conventional process such as, for example, threaded connections, welding or machined from one piece. In a preferred embodiment, the various elements of the tubular member 902 are coupled using welding. The tubular member 902 may comprise a plurality of tubular elements that are coupled end to end. The various elements of the tubular member 915 may be coupled using any  
20 number of conventional process such as, for example, threaded connections, welding or machined from one piece. In a preferred embodiment, the various elements of the tubular member 915 are coupled using welding. The tubular member 915 may comprise a plurality of tubular elements that are coupled end to end. The tubular members 902 and 915 may be coupled using any number of  
25 conventional process such as, for example, threaded connections, welding or machined from one piece.

The support member 904 preferably includes an innerstring adapter 916, a fluid passage 918, an upper guide 920, and a coupling 922. During operation of the apparatus 900, the support member 904 preferably supports the apparatus 900  
30 during movement of the apparatus 900 within a wellbore. The support member 904 preferably has a substantially annular cross-section.

WO 01/04535

PCT/US00/18635

The support member 904 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield tubulars, low alloy steel, coiled tubing or stainless steel. In a preferred embodiment, the support member 904 is fabricated from low alloy steel in order  
5 to optimally provide high yield strength.

The innerstring adaptor 916 preferably is coupled to and supported by a conventional drill string support from a surface location. The innerstring adaptor 916 may be coupled to a conventional drill string support 971 by a threaded connection 970.

10 The fluid passage 918 is preferably used to convey fluids and other materials to and from the apparatus 900. In a preferred embodiment, the fluid passage 918 is fluidically coupled to the fluid passage 952. In a preferred embodiment, the fluid passage 918 is used to convey hardenable fluidic sealing materials to and from the apparatus 900. In a particularly preferred embodiment, the fluid passage 918 may  
15 include one or more pressure relief passages (not illustrated) to release fluid pressure during positioning of the apparatus 900 within a wellbore. In a preferred embodiment, the fluid passage 918 is positioned along a longitudinal centerline of the apparatus 900. In a preferred embodiment, the fluid passage 918 is selected to permit the conveyance of hardenable fluidic materials at operating pressures  
20 ranging from about 0 to 9,000 psi.

The upper guide 920 is coupled to an upper portion of the support member 904. The upper guide 920 preferably is adapted to center the support member 904 within the tubular member 915. The upper guide 920 may comprise any number of conventional guide members modified in accordance with the teachings of the  
25 present disclosure. In a preferred embodiment, the upper guide 920 comprises an innerstring adapter available from Halliburton Energy Services in Dallas, TX order to optimally guide the apparatus 900 within the tubular member 915.

The coupling 922 couples the support member 904 to the mandrel 906. The coupling 922 preferably comprises a conventional threaded connection.

30 The various elements of the support member 904 may be coupled using any number of conventional processes such as, for example, welding, threaded

connections or machined from one piece. In a preferred embodiment, the various elements of the support member 904 are coupled using threaded connections.

The mandrel 906 preferably includes a retainer 924, a rubber cup 926, an expansion cone 928, a lower cone retainer 930, a body of cement 932, a lower guide  
5 934, an extension sleeve 936, a spacer 938, a housing 940, a sealing sleeve 942, an upper cone retainer 944, a lubricator mandrel 946, a lubricator sleeve 948, a guide 950, and a fluid passage 952.

The retainer 924 is coupled to the lubricator mandrel 946, lubricator sleeve 948, and the rubber cup 926. The retainer 924 couples the rubber cup 926 to the  
10 lubricator sleeve 948. The retainer 924 preferably has a substantially annular cross-section. The retainer 924 may comprise any number of conventional commercially available retainers such as, for example, slotted spring pins or roll pin.

The rubber cup 926 is coupled to the retainer 924, the lubricator mandrel  
15 946, and the lubricator sleeve 948. The rubber cup 926 prevents the entry of foreign materials into the interior region 972 of the tubular member 902 below the rubber cup 926. The rubber cup 926 may comprise any number of conventional commercially available rubber cups such as, for example, TP cups or Selective Injection Packer (SIP) cup. In a preferred embodiment, the rubber cup 926  
20 comprises a SIP cup available from Halliburton Energy Services in Dallas, TX in order to optimally block foreign materials.

In a particularly preferred embodiment, a body of lubricant is further provided in the interior region 972 of the tubular member 902 in order to lubricate the interface between the exterior surface of the mandrel 902 and the interior  
25 surface of the tubular members 902 and 915. The lubricant may comprise any number of conventional commercially available lubricants such as, for example, Lubriplate, chlorine based lubricants, oil based lubricants or Climax 1500 Antiseize (3100). In a preferred embodiment, the lubricant comprises Climax 1500 Antiseize (3100) available from Climax Lubricants and Equipment Co. in Houston, TX in  
30 order to optimally provide lubrication to facilitate the extrusion process.

The expansion cone 928 is coupled to the lower cone retainer 930, the body of cement 932, the lower guide 934, the extension sleeve 936, the housing 940, and

WO 01/04535

PCT/US00/18635

the upper cone retainer 944. In a preferred embodiment, during operation of the apparatus 900, the tubular members 902 and 915 are extruded off of the outer surface of the expansion cone 928. In a preferred embodiment, axial movement of the expansion cone 928 is prevented by the lower cone retainer 930, housing 940 and the upper cone retainer 944. Inner radial movement of the expansion cone 928 is prevented by the body of cement 932, the housing 940, and the upper cone retainer 944.

The expansion cone 928 preferably has a substantially annular cross section. The outside diameter of the expansion cone 928 is preferably tapered to provide a cone shape. The wall thickness of the expansion cone 928 may range, for example, from about 0.125 to 3 inches. In a preferred embodiment, the wall thickness of the expansion cone 928 ranges from about 0.25 to 0.75 inches in order to optimally provide adequate compressive strength with minimal material. The maximum and minimum outside diameters of the expansion cone 928 may range, for example, from about 1 to 47 inches. In a preferred embodiment, the maximum and minimum outside diameters of the expansion cone 928 range from about 3.5 to 19 in order to optimally provide expansion of generally available oilfield tubulars

The expansion cone 928 may be fabricated from any number of conventional commercially available materials such as, for example, ceramic, tool steel, titanium or low alloy steel. In a preferred embodiment, the expansion cone 928 is fabricated from tool steel in order to optimally provide high strength and abrasion resistance. The surface hardness of the outer surface of the expansion cone 928 may range, for example, from about 50 Rockwell C to 70 Rockwell C. In a preferred embodiment, the surface hardness of the outer surface of the expansion cone 928 ranges from about 58 Rockwell C to 62 Rockwell C in order to optimally provide high yield strength. In a preferred embodiment, the expansion cone 928 is heat treated to optimally provide a hard outer surface and a resilient interior body in order to optimally provide abrasion resistance and fracture toughness.

The lower cone retainer 930 is coupled to the expansion cone 928 and the housing 940. In a preferred embodiment, axial movement of the expansion cone 928 is prevented by the lower cone retainer 930. Preferably, the lower cone retainer 930 has a substantially annular cross-section.

The lower cone retainer 930 may be fabricated from any number of conventional commercially available materials such as, for example, ceramic, tool steel, titanium or low alloy steel. In a preferred embodiment, the lower cone retainer 930 is fabricated from tool steel in order to optimally provide high strength and abrasion resistance. The surface hardness of the outer surface of the lower cone retainer 930 may range, for example, from about 50 Rockwell C to 70 Rockwell C. In a preferred embodiment, the surface hardness of the outer surface of the lower cone retainer 930 ranges from about 58 Rockwell C to 62 Rockwell C in order to optimally provide high yield strength. In a preferred embodiment, the lower cone retainer 930 is heat treated to optimally provide a hard outer surface and a resilient interior body in order to optimally provide abrasion resistance and fracture toughness.

In a preferred embodiment, the lower cone retainer 930 and the expansion cone 928 are formed as an integral one-piece element in order to reduce the number of components and increase the overall strength of the apparatus. The outer surface of the lower cone retainer 930 preferably mates with the inner surfaces of the tubular members 902 and 915.

The body of cement 932 is positioned within the interior of the mandrel 906. The body of cement 932 provides an inner bearing structure for the mandrel 906. The body of cement 932 further may be easily drilled out using a conventional drill device. In this manner, the mandrel 906 may be easily removed using a conventional drilling device.

The body of cement 932 may comprise any number of conventional commercially available cement compounds. Alternatively, aluminum, cast iron or some other drillable metallic, composite, or aggregate material may be substituted for cement. The body of cement 932 preferably has a substantially annular cross-section.

The lower guide 934 is coupled to the extension sleeve 936 and housing 940. During operation of the apparatus 900, the lower guide 934 preferably helps guide the movement of the mandrel 906 within the tubular member 902. The lower guide 934 preferably has a substantially annular cross-section.



The lower guide 934 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield tubulars, low alloy steel or stainless steel. In a preferred embodiment, the lower guide 934 is fabricated from low alloy steel in order to optimally provide high yield strength.

- 5 The outer surface of the lower guide 934 preferably mates with the inner surface of the tubular member 902 to provide a sliding fit.

The extension sleeve 936 is coupled to the lower guide 934 and the housing 940. During operation of the apparatus 900, the extension sleeve 936 preferably helps guide the movement of the mandrel 906 within the tubular member 902.

- 10 The extension sleeve 936 preferably has a substantially annular cross-section.

The extension sleeve 936 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield tubulars, low alloy steel or stainless steel. In a preferred embodiment, the

- 15 extension sleeve 936 is fabricated from low alloy steel in order to optimally provide high yield strength. The outer surface of the extension sleeve 936 preferably mates with the inner surface of the tubular member 902 to provide a sliding fit. In a preferred embodiment, the extension sleeve 936 and the lower guide 934 are formed as an integral one-piece element in order to minimize the number of components and increase the strength of the apparatus.

- 20 The spacer 938 is coupled to the sealing sleeve 942. The spacer 938 preferably includes the fluid passage 952 and is adapted to mate with the extension tube 960 of the shoe 908. In this manner, a plug or dart can be conveyed from the surface through the fluid passages 918 and 952 into the fluid passage 962. Preferably, the spacer 938 has a substantially annular cross-section.

- 25 The spacer 938 may be fabricated from any number of conventional commercially available materials such as, for example, steel, aluminum or cast iron. In a preferred embodiment, the spacer 938 is fabricated from aluminum in order to optimally provide drillability. The end of the spacer 938 preferably mates with the end of the extension tube 960. In a preferred embodiment, the spacer  
30 938 and the sealing sleeve 942 are formed as an integral one-piece element in order to reduce the number of components and increase the strength of the apparatus.

The housing 940 is coupled to the lower guide 934, extension sleeve 936, expansion cone 928, body of cement 932, and lower cone retainer 930. During operation of the apparatus 900, the housing 940 preferably prevents inner radial motion of the expansion cone 928. Preferably, the housing 940 has a substantially  
5 annular cross-section.

The housing 940 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield tubulars, low alloy steel or stainless steel. In a preferred embodiment, the housing 940 is fabricated from low alloy steel in order to optimally provide high yield strength. In a  
10 preferred embodiment, the lower guide 934, extension sleeve 936 and housing 940 are formed as an integral one-piece element in order to minimize the number of components and increase the strength of the apparatus.

In a particularly preferred embodiment, the interior surface of the housing 940 includes one or more protrusions to facilitate the connection between the  
15 housing 940 and the body of cement 932.

The sealing sleeve 942 is coupled to the support member 904, the body of cement 932, the spacer 938, and the upper cone retainer 944. During operation of the apparatus, the sealing sleeve 942 preferably provides support for the mandrel 906. The sealing sleeve 942 is preferably coupled to the support member 904 using  
20 the coupling 922. Preferably, the sealing sleeve 942 has a substantially annular cross-section.

The sealing sleeve 942 may be fabricated from any number of conventional commercially available materials such as, for example, steel, aluminum or cast iron. In a preferred embodiment, the sealing sleeve 942 is fabricated from  
25 aluminum in order to optimally provide drillability of the sealing sleeve 942.

In a particularly preferred embodiment, the outer surface of the sealing sleeve 942 includes one or more protrusions to facilitate the connection between the sealing sleeve 942 and the body of cement 932.

In a particularly preferred embodiment, the spacer 938 and the sealing  
30 sleeve 942 are integrally formed as a one-piece element in order to minimize the number of components.

The upper cone retainer 944 is coupled to the expansion cone 928, the sealing sleeve 942, and the body of cement 932. During operation of the apparatus 900, the upper cone retainer 944 preferably prevents axial motion of the expansion cone 928. Preferably, the upper cone retainer 944 has a substantially annular cross-section.

The upper cone retainer 944 may be fabricated from any number of conventional commercially available materials such as, for example, steel, aluminum or cast iron. In a preferred embodiment, the upper cone retainer 944 is fabricated from aluminum in order to optimally provide drillability of the upper cone retainer 944.

In a particularly preferred embodiment, the upper cone retainer 944 has a cross-sectional shape designed to provide increased rigidity. In a particularly preferred embodiment, the upper cone retainer 944 has a cross-sectional shape that is substantially I-shaped to provide increased rigidity and minimize the amount of material that would have to be drilled out.

The lubricator mandrel 946 is coupled to the retainer 924, the rubber cup 926, the upper cone retainer 944, the lubricator sleeve 948, and the guide 950. During operation of the apparatus 900, the lubricator mandrel 946 preferably contains the body of lubricant in the annular region 972 for lubricating the interface between the mandrel 906 and the tubular member 902. Preferably, the lubricator mandrel 946 has a substantially annular cross-section.

The lubricator mandrel 946 may be fabricated from any number of conventional commercially available materials such as, for example, steel, aluminum or cast iron. In a preferred embodiment, the lubricator mandrel 946 is fabricated from aluminum in order to optimally provide drillability of the lubricator mandrel 946.

The lubricator sleeve 948 is coupled to the lubricator mandrel 946, the retainer 924, the rubber cup 926, the upper cone retainer 944, the lubricator sleeve 948, and the guide 950. During operation of the apparatus 900, the lubricator sleeve 948 preferably supports the rubber cup 926. Preferably, the lubricator sleeve 948 has a substantially annular cross-section.

The lubricator sleeve 948 may be fabricated from any number of conventional commercially available materials such as, for example, steel, aluminum or cast iron. In a preferred embodiment, the lubricator sleeve 948 is fabricated from aluminum in order to optimally provide drillability of the lubricator sleeve 948.

As illustrated in Fig. 9c, the lubricator sleeve 948 is supported by the lubricator mandrel 946. The lubricator sleeve 948 in turn supports the rubber cup 926. The retainer 924 couples the rubber cup 926 to the lubricator sleeve 948. In a preferred embodiment, seals 949a and 949b are provided between the lubricator mandrel 946, lubricator sleeve 948, and rubber cup 926 in order to optimally seal off the interior region 972 of the tubular member 902.

The guide 950 is coupled to the lubricator mandrel 946, the retainer 924, and the lubricator sleeve 948. During operation of the apparatus 900, the guide 950 preferably guides the apparatus on the support member 904. Preferably, the guide 950 has a substantially annular cross-section.

The guide 950 may be fabricated from any number of conventional commercially available materials such as, for example, steel, aluminum or cast iron. In a preferred embodiment, the guide 950 is fabricated from aluminum in order to optimally provide drillability of the guide 950.

The fluid passage 952 is coupled to the mandrel 906. During operation of the apparatus, the fluid passage 952 preferably conveys hardenable fluidic materials. In a preferred embodiment, the fluid passage 952 is positioned about the centerline of the apparatus 900. In a particularly preferred embodiment, the fluid passage 952 is adapted to convey hardenable fluidic materials at pressures and flow rate ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/min in order to optimally provide pressures and flow rates to displace and circulate fluids during the installation of the apparatus 900.

The various elements of the mandrel 906 may be coupled using any number of conventional process such as, for example, threaded connections, welded connections or cementing. In a preferred embodiment, the various elements of the mandrel 906 are coupled using threaded connections and cementing.

The shoe 908 preferably includes a housing 954, a body of cement 956, a sealing sleeve 958, an extension tube 960, a fluid passage 962, and one or more outlet jets 964.

5 The housing 954 is coupled to the body of cement 956 and the lower portion 914 of the tubular member 902. During operation of the apparatus 900, the housing 954 preferably couples the lower portion of the tubular member 902 to the shoe 908 to facilitate the extrusion and positioning of the tubular member 902. Preferably, the housing 954 has a substantially annular cross-section.

10 The housing 954 may be fabricated from any number of conventional commercially available materials such as, for example, steel or aluminum. In a preferred embodiment, the housing 954 is fabricated from aluminum in order to optimally provide drillability of the housing 954.

15 In a particularly preferred embodiment, the interior surface of the housing 954 includes one or more protrusions to facilitate the connection between the body of cement 956 and the housing 954.

The body of cement 956 is coupled to the housing 954, and the sealing sleeve 958. In a preferred embodiment, the composition of the body of cement 956 is selected to permit the body of cement to be easily drilled out using conventional drilling machines and processes.

20 The composition of the body of cement 956 may include any number of conventional cement compositions. In an alternative embodiment, a drillable material such as, for example, aluminum or iron may be substituted for the body of cement 956.

25 The sealing sleeve 958 is coupled to the body of cement 956, the extension tube 960, the fluid passage 962, and one or more outlet jets 964. During operation of the apparatus 900, the sealing sleeve 958 preferably is adapted to convey a hardenable fluidic material from the fluid passage 952 into the fluid passage 962 and then into the outlet jets 964 in order to inject the hardenable fluidic material into an annular region external to the tubular member 902. In a preferred 30 embodiment, during operation of the apparatus 900, the sealing sleeve 958 further includes an inlet geometry that permits a conventional plug or dart 974 to become lodged in the inlet of the sealing sleeve 958. In this manner, the fluid passage 962

may be blocked thereby fluidically isolating the interior region 966 of the tubular member 902.

In a preferred embodiment, the sealing sleeve 958 has a substantially annular cross-section. The sealing sleeve 958 may be fabricated from any number of conventional commercially available materials such as, for example, steel, aluminum or cast iron. In a preferred embodiment, the sealing sleeve 958 is fabricated from aluminum in order to optimally provide drillability of the sealing sleeve 958.

The extension tube 960 is coupled to the sealing sleeve 958, the fluid passage 962, and one or more outlet jets 964. During operation of the apparatus 900, the extension tube 960 preferably is adapted to convey a hardenable fluidic material from the fluid passage 952 into the fluid passage 962 and then into the outlet jets 964 in order to inject the hardenable fluidic material into an annular region external to the tubular member 902. In a preferred embodiment, during operation of the apparatus 900, the sealing sleeve 960 further includes an inlet geometry that permits a conventional plug or dart 974 to become lodged in the inlet of the sealing sleeve 958. In this manner, the fluid passage 962 is blocked thereby fluidically isolating the interior region 966 of the tubular member 902. In a preferred embodiment, one end of the extension tube 960 mates with one end of the spacer 938 in order to optimally facilitate the transfer of material between the two.

In a preferred embodiment, the extension tube 960 has a substantially annular cross-section. The extension tube 960 may be fabricated from any number of conventional commercially available materials such as, for example, steel, aluminum or cast iron. In a preferred embodiment, the extension tube 960 is fabricated from aluminum in order to optimally provide drillability of the extension tube 960.

The fluid passage 962 is coupled to the sealing sleeve 958, the extension tube 960, and one or more outlet jets 964. During operation of the apparatus 900, the fluid passage 962 is preferably conveys hardenable fluidic materials. In a preferred embodiment, the fluid passage 962 is positioned about the centerline of the apparatus 900. In a particularly preferred embodiment, the fluid passage 962

WO 01/04535

PCT/US00/18635

is adapted to convey hardenable fluidic materials at pressures and flow rate ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/min in order to optimally provide fluids at operationally efficient rates.

5 The outlet jets 964 are coupled to the sealing sleeve 958, the extension tube 960, and the fluid passage 962. During operation of the apparatus 900, the outlet jets 964 preferably convey hardenable fluidic material from the fluid passage 962 to the region exterior of the apparatus 900. In a preferred embodiment, the shoe 908 includes a plurality of outlet jets 964.

10 In a preferred embodiment, the outlet jets 964 comprise passages drilled in the housing 954 and the body of cement 956 in order to simplify the construction of the apparatus 900.

The various elements of the shoe 908 may be coupled using any number of conventional process such as, for example, threaded connections; cement or machined from one piece of material. In a preferred embodiment, the various  
15 elements of the shoe 908 are coupled using cement.

In a preferred embodiment, the assembly 900 is operated substantially as described above with reference to Figs. 1-8 to create a new section of casing in a wellbore or to repair a wellbore casing or pipeline.

20 In particular, in order to extend a wellbore into a subterranean formation, a drill string is used in a well known manner to drill out material from the subterranean formation to form a new section.

The apparatus 900 for forming a wellbore casing in a subterranean formation is then positioned in the new section of the wellbore. In a particularly preferred embodiment, the apparatus 900 includes the tubular member 915. In a  
25 preferred embodiment, a hardenable fluidic sealing hardenable fluidic sealing material is then pumped from a surface location into the fluid passage 918. The hardenable fluidic sealing material then passes from the fluid passage 918 into the interior region 966 of the tubular member 902 below the mandrel 906. The hardenable fluidic sealing material then passes from the interior region 966 into  
30 the fluid passage 962. The hardenable fluidic sealing material then exits the apparatus 900 via the outlet jets 964 and fills an annular region between the exterior of the tubular member 902 and the interior wall of the new section of the

wellbore. Continued pumping of the hardenable fluidic sealing material causes the material to fill up at least a portion of the annular region.

The hardenable fluidic sealing material is preferably pumped into the annular region at pressures and flow rates ranging, for example, from about 0 to 5,000 psi and 0 to 1,500 gallons/min, respectively. In a preferred embodiment, the hardenable fluidic sealing material is pumped into the annular region at pressures and flow rates that are designed for the specific wellbore section in order to optimize the displacement of the hardenable fluidic sealing material while not creating high enough circulating pressures such that circulation might be lost and that could cause the wellbore to collapse. The optimum pressures and flow rates are preferably determined using conventional empirical methods.

The hardenable fluidic sealing material may comprise any number of conventional commercially available hardenable fluidic sealing materials such as, for example, slag mix, cement or epoxy. In a preferred embodiment, the hardenable fluidic sealing material comprises blended cements designed specifically for the well section being lined available from Halliburton Energy Services in Dallas, TX in order to optimally provide support for the new tubular member while also maintaining optimal flow characteristics so as to minimize operational difficulties during the displacement of the cement in the annular region. The optimum composition of the blended cements is preferably determined using conventional empirical methods.

The annular region preferably is filled with the hardenable fluidic sealing material in sufficient quantities to ensure that, upon radial expansion of the tubular member 902, the annular region of the new section of the wellbore will be filled with hardenable material.

Once the annular region has been adequately filled with hardenable fluidic sealing material, a plug or dart 974, or other similar device, preferably is introduced into the fluid passage 962 thereby fluidically isolating the interior region 966 of the tubular member 902 from the external annular region. In a preferred embodiment, a non hardenable fluidic material is then pumped into the interior region 966 causing the interior region 966 to pressurize. In a particularly preferred embodiment, the plug or dart 974, or other similar device, preferably is



WO 01/04535

PCT/US00/18635

introduced into the fluid passage 962 by introducing the plug or dart 974, or other similar device into the non hardenable fluidic material. In this manner, the amount of cured material within the interior of the tubular members 902 and 915 is minimized.

- 5        Once the interior region 966 becomes sufficiently pressurized, the tubular members 902 and 915 are extruded off of the mandrel 906. The mandrel 906 may be fixed or it may be expandable. During the extrusion process, the mandrel 906 is raised out of the expanded portions of the tubular members 902 and 915 using the support member 904. During this extrusion process, the shoe 908 is preferably  
10 substantially stationary.

- The plug or dart 974 is preferably placed into the fluid passage 962 by introducing the plug or dart 974 into the fluid passage 918 at a surface location in a conventional manner. The plug or dart 974 may comprise any number of conventional commercially available devices for plugging a fluid passage such as,  
15 for example, Multiple Stage Cementer (MSC) latch-down plug, Omega latch-down plug or three-wiper latch down plug modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the plug or dart 974 comprises a MSC latch-down plug available from Halliburton Energy Services in Dallas, TX.

- After placement of the plug or dart 974 in the fluid passage 962, the non  
20 hardenable fluidic material is preferably pumped into the interior region 966 at pressures and flow rates ranging from approximately 500 to 9,000 psi and 40 to 3,000 gallons/min in order to optimally extrude the tubular members 902 and 915 off of the mandrel 906.

- For typical tubular members 902 and 915, the extrusion of the tubular  
25 members 902 and 915 off of the expandable mandrel will begin when the pressure of the interior region 966 reaches approximately 500 to 9,000 psi. In a preferred embodiment, the extrusion of the tubular members 902 and 915 off of the mandrel 906 begins when the pressure of the interior region 966 reaches approximately 1,200 to 8,500 psi with a flow rate of about 40 to 1250 gallons/minute.

- 30        During the extrusion process, the mandrel 906 may be raised out of the expanded portions of the tubular members 902 and 915 at rates ranging, for example, from about 0 to 5 ft/sec. In a preferred embodiment, during the extrusion

WO 01/04535

PCT/US00/18635

process, the mandrel 906 is raised out of the expanded portions of the tubular members 902 and 915 at rates ranging from about 0 to 2 ft/sec in order to optimally provide pulling speed fast enough to permit efficient operation and permit full expansion of the tubular members 902 and 915 prior to curing of the  
5 hardenable fluidic sealing material; but not so fast that timely adjustment of operating parameters during operation is prevented.

When the upper end portion of the tubular member 915 is extruded off of the mandrel 906, the outer surface of the upper end portion of the tubular member 915 will preferably contact the interior surface of the lower end portion of the  
10 existing casing to form an fluid tight overlapping joint. The contact pressure of the overlapping joint may range, for example, from approximately 50 to 20,000 psi. In a preferred embodiment, the contact pressure of the overlapping joint between the upper end of the tubular member 915 and the existing section of wellbore casing ranges from approximately 400 to 10,000 psi in order to optimally provide contact  
15 pressure to activate the sealing members and provide optimal resistance such that the tubular member 915 and existing wellbore casing will carry typical tensile and compressive loads.

In a preferred embodiment, the operating pressure and flow rate of the non hardenable fluidic material will be controllably ramped down when the mandrel  
20 906 reaches the upper end portion of the tubular member 915. In this manner, the sudden release of pressure caused by the complete extrusion of the tubular member 915 off of the expandable mandrel 906 can be minimized. In a preferred embodiment, the operating pressure is reduced in a substantially linear fashion from 100% to about 10% during the end of the extrusion process beginning when  
25 the mandrel 906 has completed approximately all but about the last 5 feet of the extrusion process.

In an alternative preferred embodiment, the operating pressure and/or flow rate of the hardenable fluidic sealing material and/or the non hardenable fluidic material are controlled during all phases of the operation of the apparatus 900 to  
30 minimize shock.

Alternatively, or in combination, a shock absorber is provided in the support member 904 in order to absorb the shock caused by the sudden release of pressure.

WO 01/04535

PCT/US00/18635

Alternatively, or in combination, a mandrel catching structure is provided above the support member 904 in order to catch or at least decelerate the mandrel 906.

Once the extrusion process is completed, the mandrel 906 is removed from the wellbore. In a preferred embodiment, either before or after the removal of the mandrel 906, the integrity of the fluidic seal of the overlapping joint between the upper portion of the tubular member 915 and the lower portion of the existing casing is tested using conventional methods. If the fluidic seal of the overlapping joint between the upper portion of the tubular member 915 and the lower portion of the existing casing is satisfactory, then the uncured portion of any of the hardenable fluidic sealing material within the expanded tubular member 915 is then removed in a conventional manner. The hardenable fluidic sealing material within the annular region between the expanded tubular member 915 and the existing casing and new section of wellbore is then allowed to cure.

Preferably any remaining cured hardenable fluidic sealing material within the interior of the expanded tubular members 902 and 915 is then removed in a conventional manner using a conventional drill string. The resulting new section of casing preferably includes the expanded tubular members 902 and 915 and an outer annular layer of cured hardenable fluidic sealing material. The bottom portion of the apparatus 900 comprising the shoe 908 may then be removed by drilling out the shoe 908 using conventional drilling methods.

In an alternative embodiment, during the extrusion process, it may be necessary to remove the entire apparatus 900 from the interior of the wellbore due to a malfunction. In this circumstance, a conventional drill string is used to drill out the interior sections of the apparatus 900 in order to facilitate the removal of the remaining sections. In a preferred embodiment, the interior elements of the apparatus 900 are fabricated from materials such as, for example, cement and aluminum, that permit a conventional drill string to be employed to drill out the interior components.

In particular, in a preferred embodiment, the composition of the interior sections of the mandrel 906 and shoe 908, including one or more of the body of cement 932, the spacer 938, the sealing sleeve 942, the upper cone retainer 944,

the lubricator mandrel 946, the lubricator sleeve 948, the guide 950, the housing 954, the body of cement 956, the sealing sleeve 958, and the extension tube 960, are selected to permit at least some of these components to be drilled out using conventional drilling methods and apparatus. In this manner, in the event of a malfunction downhole, the apparatus 900 may be easily removed from the wellbore.

Referring now to Figs. 10a, 10b, 10c, 10d, 10e, 10f, and 10g a method and apparatus for creating a tie-back liner in a wellbore will now be described. As illustrated in Fig. 10a, a wellbore 1000 positioned in a subterranean formation 1002 includes a first casing 1004 and a second casing 1006.

The first casing 1004 preferably includes a tubular liner 1008 and a cement annulus 1010. The second casing 1006 preferably includes a tubular liner 1012 and a cement annulus 1014. In a preferred embodiment, the second casing 1006 is formed by expanding a tubular member substantially as described above with reference to Figs. 1-9c or below with reference to Figs. 11a-11f.

In a particularly preferred embodiment, an upper portion of the tubular liner 1012 overlaps with a lower portion of the tubular liner 1008. In a particularly preferred embodiment, an outer surface of the upper portion of the tubular liner 1012 includes one or more sealing members 1016 for providing a fluidic seal between the tubular liners 1008 and 1012.

Referring to Fig. 10b, in order to create a tie-back liner that extends from the overlap between the first and second casings, 1004 and 1006, an apparatus 1100 is preferably provided that includes an expandable mandrel or pig 1105, a tubular member 1110, a shoe 1115, one or more cup seals 1120, a fluid passage 1130, a fluid passage 1135, one or more fluid passages 1140, seals 1145, and a support member 1150.

The expandable mandrel or pig 1105 is coupled to and supported by the support member 1150. The expandable mandrel 1105 is preferably adapted to controllably expand in a radial direction. The expandable mandrel 1105 may comprise any number of conventional commercially available expandable mandrels modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the expandable mandrel 1105 comprises a hydraulic expansion tool

substantially as disclosed in U.S. Pat. No. 5,348,095, the disclosure of which is incorporated herein by reference, modified in accordance with the teachings of the present disclosure.

The tubular member 1110 is coupled to and supported by the expandable  
5 mandrel 1105. The tubular member 1105 is expanded in the radial direction and extruded off of the expandable mandrel 1105. The tubular member 1110 may be fabricated from any number of materials such as, for example, Oilfield Country Tubular Goods, 13 chromium tubing or plastic piping. In a preferred embodiment, the tubular member 1110 is fabricated from Oilfield Country Tubular Goods.

10 The inner and outer diameters of the tubular member 1110 may range, for example, from approximately 0.75 to 47 inches and 1.05 to 48 inches, respectively. In a preferred embodiment, the inner and outer diameters of the tubular member 1110 range from about 3 to 15.5 inches and 3.5 to 16 inches, respectively in order to optimally provide coverage for typical oilfield casing sizes. The tubular member  
15 1110 preferably comprises a solid member.

In a preferred embodiment, the upper end portion of the tubular member 1110 is slotted, perforated, or otherwise modified to catch or slow down the mandrel 1105 when it completes the extrusion of tubular member 1110. In a preferred embodiment, the length of the tubular member 1110 is limited to  
20 minimize the possibility of buckling. For typical tubular member 1110 materials, the length of the tubular member 1110 is preferably limited to between about 40 to 20,000 feet in length.

The shoe 1115 is coupled to the expandable mandrel 1105 and the tubular member 1110. The shoe 1115 includes the fluid passage 1135. The shoe 1115 may  
25 comprise any number of conventional commercially available shoes such as, for example, Super Seal II float shoe, Super Seal II Down-Jet float shoe or a guide shoe with a sealing sleeve for a latch down plug modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the shoe 1115 comprises an aluminum down-jet guide shoe with a sealing sleeve for a latch-down  
30 plug with side ports radiating off of the exit flow port available from Halliburton Energy Services in Dallas, TX, modified in accordance with the teachings of the present disclosure, in order to optimally guide the tubular member 1100 to the

overlap between the tubular member 1100 and the casing 1012, optimally fluidically isolate the interior of the tubular member 1100 after the latch down plug has seated, and optimally permit drilling out of the shoe 1115 after completion of the expansion and cementing operations.

5        In a preferred embodiment, the shoe 1115 includes one or more side outlet ports 1140 in fluidic communication with the fluid passage 1135. In this manner, the shoe 1115 injects hardenable fluidic sealing material into the region outside the shoe 1115 and tubular member 1110. In a preferred embodiment, the shoe 1115 includes one or more of the fluid passages 1140 each having an inlet geometry that  
10       can receive a dart and/or a ball sealing member. In this manner, the fluid passages 1140 can be sealed off by introducing a plug, dart and/or ball sealing elements into the fluid passage 1130.

      The cup seal 1120 is coupled to and supported by the support member 1150. The cup seal 1120 prevents foreign materials from entering the interior region of  
15       the tubular member 1110 adjacent to the expandable mandrel 1105. The cup seal 1120 may comprise any number of conventional commercially available cup seals such as, for example, TP cups or Selective Injection Packer (SIP) cups modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the cup seal 1120 comprises a SIP cup, available from Halliburton  
20       Energy Services in Dallas, TX in order to optimally provide a barrier to debris and contain a body of lubricant.

      The fluid passage 1130 permits fluidic materials to be transported to and from the interior region of the tubular member 1110 below the expandable mandrel 1105. The fluid passage 1130 is coupled to and positioned within the  
25       support member 1150 and the expandable mandrel 1105. The fluid passage 1130 preferably extends from a position adjacent to the surface to the bottom of the expandable mandrel 1105. The fluid passage 1130 is preferably positioned along a centerline of the apparatus 1100. The fluid passage 1130 is preferably selected to transport materials such as cement, drilling mud or epoxies at flow rates and  
30       pressures ranging from about 0 to 3,000 gallons/minute and 0 to 9,000 psi in order to optimally provide sufficient operating pressures to circulate fluids at operationally efficient rates.

WO 01/04535

PCT/US00/18635

The fluid passage 1135 permits fluidic materials to be transmitted from fluid passage 1130 to the interior of the tubular member 1110 below the mandrel 1105.

The fluid passages 1140 permits fluidic materials to be transported to and from the region exterior to the tubular member 1110 and shoe 1115. The fluid passages 1140 are coupled to and positioned within the shoe 1115 in fluidic communication with the interior region of the tubular member 1110 below the expandable mandrel 1105. The fluid passages 1140 preferably have a cross-sectional shape that permits a plug, or other similar device, to be placed in the fluid passages 1140 to thereby block further passage of fluidic materials. In this manner, the interior region of the tubular member 1110 below the expandable mandrel 1105 can be fluidically isolated from the region exterior to the tubular member 1105. This permits the interior region of the tubular member 1110 below the expandable mandrel 1105 to be pressurized.

The fluid passages 1140 are preferably positioned along the periphery of the shoe 1115. The fluid passages 1140 are preferably selected to convey materials such as cement, drilling mud or epoxies at flow rates and pressures ranging from about 0 to 3,000 gallons/minute and 0 to 9,000 psi in order to optimally fill the annular region between the tubular member 1110 and the tubular liner 1008 with fluidic materials. In a preferred embodiment, the fluid passages 1140 include an inlet geometry that can receive a dart and/or a ball sealing member. In this manner, the fluid passages 1140 can be sealed off by introducing a plug, dart and/or ball sealing elements into the fluid passage 1130. In a preferred embodiment, the apparatus 1100 includes a plurality of fluid passage 1140.

In an alternative embodiment, the base of the shoe 1115 includes a single inlet passage coupled to the fluid passages 1140 that is adapted to receive a plug, or other similar device, to permit the interior region of the tubular member 1110 to be fluidically isolated from the exterior of the tubular member 1110.

The seals 1145 are coupled to and supported by a lower end portion of the tubular member 1110. The seals 1145 are further positioned on an outer surface of the lower end portion of the tubular member 1110. The seals 1145 permit the overlapping joint between the upper end portion of the casing 1012 and the lower end portion of the tubular member 1110 to be fluidically sealed.

The seals 1145 may comprise any number of conventional commercially available seals such as, for example, lead, rubber, Teflon or epoxy seals modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the seals 1145 comprise seals molded from Stratalock epoxy available  
5 from Halliburton Energy Services in Dallas, TX in order to optimally provide a hydraulic seal in the overlapping joint and optimally provide load carrying capacity to withstand the range of typical tensile and compressive loads.

In a preferred embodiment, the seals 1145 are selected to optimally provide a sufficient frictional force to support the expanded tubular member 1110 from the  
10 tubular liner 1008. In a preferred embodiment, the frictional force provided by the seals 1145 ranges from about 1,000 to 1,000,000 lbf in tension and compression in order to optimally support the expanded tubular member 1110.

The support member 1150 is coupled to the expandable mandrel 1105, tubular member 1110, shoe 1115, and seal 1120. The support member 1150  
15 preferably comprises an annular member having sufficient strength to carry the apparatus 1100 into the wellbore 1000. In a preferred embodiment, the support member 1150 further includes one or more conventional centralizers (not illustrated) to help stabilize the tubular member 1110.

In a preferred embodiment, a quantity of lubricant 1150 is provided in the  
20 annular region above the expandable mandrel 1105 within the interior of the tubular member 1110. In this manner, the extrusion of the tubular member 1110 off of the expandable mandrel 1105 is facilitated. The lubricant 1150 may comprise any number of conventional commercially available lubricants such as, for example, Lubriplate, chlorine based lubricants or Climax 1500 Antiseize (3100).  
25 In a preferred embodiment, the lubricant 1150 comprises Climax 1500 Antiseize (3100) available from Climax Lubricants and Equipment Co. in Houston, TX in order to optimally provide lubrication for the extrusion process.

In a preferred embodiment, the support member 1150 is thoroughly cleaned prior to assembly to the remaining portions of the apparatus 1100. In this  
30 manner, the introduction of foreign material into the apparatus 1100 is minimized. This minimizes the possibility of foreign material clogging the various flow



passages and valves of the apparatus 1100 and to ensure that no foreign material interferes with the expansion mandrel 1105 during the extrusion process.

In a particularly preferred embodiment, the apparatus 1100 includes a packer 1155 coupled to the bottom section of the shoe 1115 for fluidically isolating the region of the wellbore 1000 below the apparatus 1100. In this manner, fluidic materials are prevented from entering the region of the wellbore 1000 below the apparatus 1100. The packer 1155 may comprise any number of conventional commercially available packers such as, for example, EZ Drill Packer, EZ SV Packer or a drillable cement retainer. In a preferred embodiment, the packer 1155 comprises an EZ Drill Packer available from Halliburton Energy Services in Dallas, TX. In an alternative embodiment, a high gel strength pill may be set below the tie-back in place of the packer 1155. In another alternative embodiment, the packer 1155 may be omitted.

In a preferred embodiment, before or after positioning the apparatus 1100 within the wellbore 1100, a couple of wellbore volumes are circulated in order to ensure that no foreign materials are located within the wellbore 1000 that might clog up the various flow passages and valves of the apparatus 1100 and to ensure that no foreign material interferes with the operation of the expansion mandrel 1105.

As illustrated in Fig. 10c, a hardenable fluidic sealing material 1160 is then pumped from a surface location into the fluid passage 1130. The material 1160 then passes from the fluid passage 1130 into the interior region of the tubular member 1110 below the expandable mandrel 1105. The material 1160 then passes from the interior region of the tubular member 1110 into the fluid passages 1140. The material 1160 then exits the apparatus 1100 and fills the annular region between the exterior of the tubular member 1110 and the interior wall of the tubular liner 1008. Continued pumping of the material 1160 causes the material 1160 to fill up at least a portion of the annular region.

The material 1160 may be pumped into the annular region at pressures and flow rates ranging, for example, from about 0 to 5,000 psi and 0 to 1,500 gallons/min, respectively. In a preferred embodiment, the material 1160 is pumped into the annular region at pressures and flow rates specifically designed for the

casing sizes being run, the annular spaces being filled, the pumping equipment available, and the properties of the fluid being pumped. The optimum flow rates and pressures are preferably calculated using conventional empirical methods.

The hardenable fluidic sealing material 1160 may comprise any number of  
5 conventional commercially available hardenable fluidic sealing materials such as, for example, slag mix, cement or epoxy. In a preferred embodiment, the hardenable fluidic sealing material 1160 comprises blended cements specifically designed for well section being tied-back, available from Halliburton Energy  
10 Services in Dallas, TX in order to optimally provide proper support for the tubular member 1110 while maintaining optimum flow characteristics so as to minimize operational difficulties during the displacement of cement in the annular region. The optimum blend of the blended cements are preferably determined using conventional empirical methods.

The annular region may be filled with the material 1160 in sufficient  
15 quantities to ensure that, upon radial expansion of the tubular member 1110, the annular region will be filled with material 1160.

As illustrated in Fig. 10d, once the annular region has been adequately filled with material 1160, one or more plugs 1165, or other similar devices, preferably are introduced into the fluid passages 1140 thereby fluidically isolating the interior  
20 region of the tubular member 1110 from the annular region external to the tubular member 1110. In a preferred embodiment, a non hardenable fluidic material 1161 is then pumped into the interior region of the tubular member 1110 below the mandrel 1105 causing the interior region to pressurize. In a particularly preferred embodiment, the one or more plugs 1165, or other similar devices, are introduced  
25 into the fluid passage 1140 with the introduction of the non hardenable fluidic material. In this manner, the amount of hardenable fluidic material within the interior of the tubular member 1110 is minimized.

As illustrated in Fig. 10e, once the interior region becomes sufficiently pressurized, the tubular member 1110 is extruded off of the expandable mandrel  
30 1105. During the extrusion process, the expandable mandrel 1105 is raised out of the expanded portion of the tubular member 1110.

The plugs 1165 are preferably placed into the fluid passages 1140 by introducing the plugs 1165 into the fluid passage 1130 at a surface location in a conventional manner. The plugs 1165 may comprise any number of conventional commercially available devices from plugging a fluid passage such as, for example,  
5 brass balls, plugs, rubber balls, or darts modified in accordance with the teachings of the present disclosure.

In a preferred embodiment, the plugs 1165 comprise low density rubber balls. In an alternative embodiment, for a shoe 1105 having a common central inlet passage, the plugs 1165 comprise a single latch down dart.

10 After placement of the plugs 1165 in the fluid passages 1140, the non hardenable fluidic material 1161 is preferably pumped into the interior region of the tubular member 1110 below the mandrel 1105 at pressures and flow rates ranging from approximately 500 to 9,000 psi and 40 to 3,000 gallons/min.

In a preferred embodiment, after placement of the plugs 1165 in the fluid passages  
15 1140, the non hardenable fluidic material 1161 is preferably pumped into the interior region of the tubular member 1110 below the mandrel 1105 at pressures and flow rates ranging from approximately 1200 to 8500 psi and 40 to 1250 gallons/min in order to optimally provide extrusion of typical tubulars.

For typical tubular members 1110, the extrusion of the tubular member  
20 1110 off of the expandable mandrel 1105 will begin when the pressure of the interior region of the tubular member 1110 below the mandrel 1105 reaches, for example, approximately 1200 to 8500 psi. In a preferred embodiment, the extrusion of the tubular member 1110 off of the expandable mandrel 1105 begins when the pressure of the interior region of the tubular member 1110 below the  
25 mandrel 1105 reaches approximately 1200 to 8500 psi.

During the extrusion process, the expandable mandrel 1105 may be raised out of the expanded portion of the tubular member 1110 at rates ranging, for example, from about 0 to 5 ft/sec. In a preferred embodiment, during the extrusion process, the expandable mandrel 1105 is raised out of the expanded portion of the  
30 tubular member 1110 at rates ranging from about 0 to 2 ft/sec in order to optimally provide permit adjustment of operational parameters, and optimally ensure that the extrusion process will be completed before the material 1160 cures.

In a preferred embodiment, at least a portion 1180 of the tubular member 1110 has an internal diameter less than the outside diameter of the mandrel 1105. In this manner, when the mandrel 1105 expands the section 1180 of the tubular member 1110, at least a portion of the expanded section 1180 effects a seal with  
5 at least the wellbore casing 1012. In a particularly preferred embodiment, the seal is effected by compressing the seals 1016 between the expanded section 1180 and the wellbore casing 1012. In a preferred embodiment, the contact pressure of the joint between the expanded section 1180 of the tubular member 1110 and the casing 1012 ranges from about 500 to 10,000 psi in order to optimally provide  
10 pressure to activate the sealing members 1145 and provide optimal resistance to ensure that the joint will withstand typical extremes of tensile and compressive loads.

In an alternative preferred embodiment, substantially all of the entire length of the tubular member 1110 has an internal diameter less than the outside  
15 diameter of the mandrel 1105. In this manner, extrusion of the tubular member 1110 by the mandrel 1105 results in contact between substantially all of the expanded tubular member 1110 and the existing casing 1008. In a preferred embodiment, the contact pressure of the joint between the expanded tubular member 1110 and the casings 1008 and 1012 ranges from about 500 to 10,000 psi  
20 in order to optimally provide pressure to activate the sealing members 1145 and provide optimal resistance to ensure that the joint will withstand typical extremes of tensile and compressive loads.

In a preferred embodiment, the operating pressure and flow rate of the material 1161 is controllably ramped down when the expandable mandrel 1105  
25 reaches the upper end portion of the tubular member 1110. In this manner, the sudden release of pressure caused by the complete extrusion of the tubular member 1110 off of the expandable mandrel 1105 can be minimized. In a preferred embodiment, the operating pressure of the fluidic material 1161 is reduced in a substantially linear fashion from 100% to about 10% during the end  
30 of the extrusion process beginning when the mandrel 1105 has completed approximately all but about 5 feet of the extrusion process.

WO 01/04535

PCT/US00/18635

Alternatively, or in combination, a shock absorber is provided in the support member 1150 in order to absorb the shock caused by the sudden release of pressure.

Alternatively, or in combination, a mandrel catching structure is provided  
5 in the upper end portion of the tubular member 1110 in order to catch or at least decelerate the mandrel 1105.

Referring to Fig. 10f, once the extrusion process is completed, the expandable mandrel 1105 is removed from the wellbore 1000. In a preferred embodiment, either before or after the removal of the expandable mandrel 1105,  
10 the integrity of the fluidic seal of the joint between the upper portion of the tubular member 1110 and the upper portion of the tubular liner 1108 is tested using conventional methods. If the fluidic seal of the joint between the upper portion of the tubular member 1110 and the upper portion of the tubular liner  
15 1008 is satisfactory, then the uncured portion of the material 1160 within the expanded tubular member 1110 is then removed in a conventional manner. The material 1160 within the annular region between the tubular member 1110 and the tubular liner 1008 is then allowed to cure.

As illustrated in Fig. 10f, preferably any remaining cured material 1160 within the interior of the expanded tubular member 1110 is then removed in a  
20 conventional manner using a conventional drill string. The resulting tie-back liner of casing 1170 includes the expanded tubular member 1110 and an outer annular layer 1175 of cured material 1160.

As illustrated in Fig. 10g, the remaining bottom portion of the apparatus 1100 comprising the shoe 1115 and packer 1155 is then preferably removed by  
25 drilling out the shoe 1115 and packer 1155 using conventional drilling methods.

In a particularly preferred embodiment, the apparatus 1100 incorporates the apparatus 900.

Referring now to Figs. 11a-11f, an embodiment of an apparatus and method for hanging a tubular liner off of an existing wellbore casing will now be described.  
30 As illustrated in Fig. 11a, a wellbore 1200 is positioned in a subterranean formation 1205. The wellbore 1200 includes an existing cased section 1210 having a tubular casing 1215 and an annular outer layer of cement 1220.

WO 01/04535

PCT/US00/18635

In order to extend the wellbore 1200 into the subterranean formation 1205, a drill string 1225 is used in a well known manner to drill out material from the subterranean formation 1205 to form a new section 1230.

As illustrated in Fig. 11b, an apparatus 1300 for forming a wellbore casing  
5 in a subterranean formation is then positioned in the new section 1230 of the wellbore 100. The apparatus 1300 preferably includes an expandable mandrel or pig 1305, a tubular member 1310, a shoe 1315, a fluid passage 1320, a fluid passage 1330, a fluid passage 1335, seals 1340, a support member 1345, and a wiper plug 1350.

10 The expandable mandrel 1305 is coupled to and supported by the support member 1345. The expandable mandrel 1305 is preferably adapted to controllably expand in a radial direction. The expandable mandrel 1305 may comprise any number of conventional commercially available expandable mandrels modified in accordance with the teachings of the present disclosure. In a preferred  
15 embodiment, the expandable mandrel 1305 comprises a hydraulic expansion tool substantially as disclosed in U.S. Pat. No. 5,348,095, the disclosure of which is incorporated herein by reference, modified in accordance with the teachings of the present disclosure.

The tubular member 1310 is coupled to and supported by the expandable  
20 mandrel 1305. The tubular member 1310 is preferably expanded in the radial direction and extruded off of the expandable mandrel 1305. The tubular member 1310 may be fabricated from any number of materials such as, for example, Oilfield Country Tubular Goods (OCTG), 13 chromium steel tubing/casing or plastic casing. In a preferred embodiment, the tubular member 1310 is fabricated from  
25 OCTG. The inner and outer diameters of the tubular member 1310 may range, for example, from approximately 0.75 to 47 inches and 1.05 to 48 inches, respectively. In a preferred embodiment, the inner and outer diameters of the tubular member 1310 range from about 3 to 15.5 inches and 3.5 to 16 inches, respectively in order to optimally provide minimal telescoping effect in the most commonly encountered  
30 wellbore sizes.

In a preferred embodiment, the tubular member 1310 includes an upper portion 1355, an intermediate portion 1360, and a lower portion 1365. In a

preferred embodiment, the wall thickness and outer diameter of the upper portion 1355 of the tubular member 1310 range from about 3/8 to 1 1/2 inches and 3 1/2 to 16 inches, respectively. In a preferred embodiment, the wall thickness and outer diameter of the intermediate portion 1360 of the tubular member 1310 range from about 0.625 to 0.75 inches and 3 to 19 inches, respectively. In a preferred embodiment, the wall thickness and outer diameter of the lower portion 1365 of the tubular member 1310 range from about 3/8 to 1.5 inches and 3.5 to 16 inches, respectively.

In a particularly preferred embodiment, the outer diameter of the lower portion 1365 of the tubular member 1310 is significantly less than the outer diameters of the upper and intermediate portions, 1355 and 1360, of the tubular member 1310 in order to optimize the formation of a concentric and overlapping arrangement of wellbore casings. In this manner, as will be described below with reference to Figs. 12 and 13, a wellhead system is optimally provided. In a preferred embodiment, the formation of a wellhead system does not include the use of a hardenable fluidic material.

In a particularly preferred embodiment, the wall thickness of the intermediate section 1360 of the tubular member 1310 is less than or equal to the wall thickness of the upper and lower sections, 1355 and 1365, of the tubular member 1310 in order to optimally facilitate the initiation of the extrusion process and optimally permit the placement of the apparatus in areas of the wellbore having tight clearances.

The tubular member 1310 preferably comprises a solid member. In a preferred embodiment, the upper end portion 1355 of the tubular member 1310 is slotted, perforated, or otherwise modified to catch or slow down the mandrel 1305 when it completes the extrusion of tubular member 1310. In a preferred embodiment, the length of the tubular member 1310 is limited to minimize the possibility of buckling. For typical tubular member 1310 materials, the length of the tubular member 1310 is preferably limited to between about 40 to 20,000 feet in length.

The shoe 1315 is coupled to the tubular member 1310. The shoe 1315 preferably includes fluid passages 1330 and 1335. The shoe 1315 may comprise

any number of conventional commercially available shoes such as, for example, Super Seal II float shoe, Super Seal II Down-Jet float shoe or guide shoe with a sealing sleeve for a latch-down plug modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the shoe 1315 comprises an  
5 aluminum down-jet guide shoe with a sealing sleeve for a latch-down plug available from Halliburton Energy Services in Dallas, TX, modified in accordance with the teachings of the present disclosure, in order to optimally guide the tubular member 1310 into the wellbore 1200, optimally fluidically isolate the interior of the tubular member 1310, and optimally permit the complete drill out of the shoe 1315 upon  
10 the completion of the extrusion and cementing operations.

In a preferred embodiment, the shoe 1315 further includes one or more side outlet ports in fluidic communication with the fluid passage 1330. In this manner, the shoe 1315 preferably injects hardenable fluidic sealing material into the region outside the shoe 1315 and tubular member 1310. In a preferred embodiment, the  
15 shoe 1315 includes the fluid passage 1330 having an inlet geometry that can receive a fluidic sealing member. In this manner, the fluid passage 1330 can be sealed off by introducing a plug, dart and/or ball sealing elements into the fluid passage 1330.

The fluid passage 1320 permits fluidic materials to be transported to and  
20 from the interior region of the tubular member 1310 below the expandable mandrel 1305. The fluid passage 1320 is coupled to and positioned within the support member 1345 and the expandable mandrel 1305. The fluid passage 1320 preferably extends from a position adjacent to the surface to the bottom of the expandable mandrel 1305. The fluid passage 1320 is preferably positioned along  
25 a centerline of the apparatus 1300. The fluid passage 1320 is preferably selected to transport materials such as cement, drilling mud, or epoxies at flow rates and pressures ranging from about 0 to 3,000 gallons/minute and 0 to 9,000 psi in order to optimally provide sufficient operating pressures to circulate fluids at operationally efficient rates.

30 The fluid passage 1330 permits fluidic materials to be transported to and from the region exterior to the tubular member 1310 and shoe 1315. The fluid passage 1330 is coupled to and positioned within the shoe 1315 in fluidic



communication with the interior region 1370 of the tubular member 1310 below the expandable mandrel 1305. The fluid passage 1330 preferably has a cross-sectional shape that permits a plug, or other similar device, to be placed in fluid passage 1330 to thereby block further passage of fluidic materials. In this manner, 5 the interior region 1370 of the tubular member 1310 below the expandable mandrel 1305 can be fluidically isolated from the region exterior to the tubular member 1310. This permits the interior region 1370 of the tubular member 1310 below the expandable mandrel 1305 to be pressurized. The fluid passage 1330 is preferably positioned substantially along the centerline of the apparatus 1300.

10 The fluid passage 1330 is preferably selected to convey materials such as cement, drilling mud or epoxies at flow rates and pressures ranging from about 0 to 3,000 gallons/minute and 0 to 9,000 psi in order to optimally fill the annular region between the tubular member 1310 and the new section 1230 of the wellbore 1200 with fluidic materials. In a preferred embodiment, the fluid passage 1330 15 includes an inlet geometry that can receive a dart and/or a ball sealing member. In this manner, the fluid passage 1330 can be sealed off by introducing a plug, dart and/or ball sealing elements into the fluid passage 1320.

The fluid passage 1335 permits fluidic materials to be transported to and from the region exterior to the tubular member 1310 and shoe 1315. The fluid 20 passage 1335 is coupled to and positioned within the shoe 1315 in fluidic communication with the fluid passage 1330. The fluid passage 1335 is preferably positioned substantially along the centerline of the apparatus 1300. The fluid passage 1335 is preferably selected to convey materials such as cement, drilling mud or epoxies at flow rates and pressures ranging from about 0 to 3,000 25 gallons/minute and 0 to 9,000 psi in order to optimally fill the annular region between the tubular member 1310 and the new section 1230 of the wellbore 1200 with fluidic materials.

The seals 1340 are coupled to and supported by the upper end portion 1355 of the tubular member 1310. The seals 1340 are further positioned on an outer 30 surface of the upper end portion 1355 of the tubular member 1310. The seals 1340 permit the overlapping joint between the lower end portion of the casing 1215 and the upper portion 1355 of the tubular member 1310 to be fluidically sealed. The

seals 1340 may comprise any number of conventional commercially available seals such as, for example, lead, rubber, Teflon, or epoxy seals modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the seals 1340 comprise seals molded from Stratalock epoxy available from Halliburton Energy Services in Dallas, TX in order to optimally provide a hydraulic seal in the annulus of the overlapping joint while also creating optimal load bearing capability to withstand typical tensile and compressive loads.

In a preferred embodiment, the seals 1340 are selected to optimally provide a sufficient frictional force to support the expanded tubular member 1310 from the existing casing 1215. In a preferred embodiment, the frictional force provided by the seals 1340 ranges from about 1,000 to 1,000,000 lbf in order to optimally support the expanded tubular member 1310.

The support member 1345 is coupled to the expandable mandrel 1305, tubular member 1310, shoe 1315, and seals 1340. The support member 1345 preferably comprises an annular member having sufficient strength to carry the apparatus 1300 into the new section 1230 of the wellbore 1200. In a preferred embodiment, the support member 1345 further includes one or more conventional centralizers (not illustrated) to help stabilize the tubular member 1310.

In a preferred embodiment, the support member 1345 is thoroughly cleaned prior to assembly to the remaining portions of the apparatus 1300. In this manner, the introduction of foreign material into the apparatus 1300 is minimized. This minimizes the possibility of foreign material clogging the various flow passages and valves of the apparatus 1300 and to ensure that no foreign material interferes with the expansion process.

The wiper plug 1350 is coupled to the mandrel 1305 within the interior region 1370 of the tubular member 1310. The wiper plug 1350 includes a fluid passage 1375 that is coupled to the fluid passage 1320. The wiper plug 1350 may comprise one or more conventional commercially available wiper plugs such as, for example, Multiple Stage Cementer latch-down plugs, Omega latch-down plugs or three-wiper latch-down plug modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the wiper plug 1350 comprises a Multiple Stage Cementer latch-down plug available from Halliburton Energy

WO 01/04535

PCT/US00/18635

Services in Dallas, TX modified in a conventional manner for releasable attachment to the expansion mandrel 1305.

5 In a preferred embodiment, before or after positioning the apparatus 1300 within the new section 1230 of the wellbore 1200, a couple of wellbore volumes are circulated in order to ensure that no foreign materials are located within the wellbore 1200 that might clog up the various flow passages and valves of the apparatus 1300 and to ensure that no foreign material interferes with the extrusion process.

As illustrated in Fig. 11c, a hardenable fluidic sealing material 1380 is then  
10 pumped from a surface location into the fluid passage 1320. The material 1380 then passes from the fluid passage 1320, through the fluid passage 1375, and into the interior region 1370 of the tubular member 1310 below the expandable mandrel 1305. The material 1380 then passes from the interior region 1370 into the fluid passage 1330. The material 1380 then exits the apparatus 1300 via the  
15 fluid passage 1335 and fills the annular region 1390 between the exterior of the tubular member 1310 and the interior wall of the new section 1230 of the wellbore 1200. Continued pumping of the material 1380 causes the material 1380 to fill up at least a portion of the annular region 1390.

The material 1380 may be pumped into the annular region 1390 at  
20 pressures and flow rates ranging, for example, from about 0 to 5000 psi and 0 to 1,500 gallons/min, respectively. In a preferred embodiment, the material 1380 is pumped into the annular region 1390 at pressures and flow rates ranging from about 0 to 5000 psi and 0 to 1,500 gallons/min, respectively, in order to optimally fill the annular region between the tubular member 1310 and the new section 1230  
25 of the wellbore 1200 with the hardenable fluidic sealing material 1380.

The hardenable fluidic sealing material 1380 may comprise any number of conventional commercially available hardenable fluidic sealing materials such as, for example, slag mix, cement or epoxy. In a preferred embodiment, the hardenable fluidic sealing material 1380 comprises blended cements designed  
30 specifically for the well section being drilled and available from Halliburton Energy Services in order to optimally provide support for the tubular member 1310 during

displacement of the material 1380 in the annular region 1390. The optimum blend of the cement is preferably determined using conventional empirical methods.

The annular region 1390 preferably is filled with the material 1380 in sufficient quantities to ensure that, upon radial expansion of the tubular member 1310, the annular region 1390 of the new section 1230 of the wellbore 1200 will be filled with material 1380.

As illustrated in Fig. 11d, once the annular region 1390 has been adequately filled with material 1380, a wiper dart 1395, or other similar device, is introduced into the fluid passage 1320. The wiper dart 1395 is preferably pumped through the fluid passage 1320 by a non hardenable fluidic material 1381. The wiper dart 1395 then preferably engages the wiper plug 1350.

As illustrated in Fig. 11e, in a preferred embodiment, engagement of the wiper dart 1395 with the wiper plug 1350 causes the wiper plug 1350 to decouple from the mandrel 1305. The wiper dart 1395 and wiper plug 1350 then preferably will lodge in the fluid passage 1330, thereby blocking fluid flow through the fluid passage 1330, and fluidically isolating the interior region 1370 of the tubular member 1310 from the annular region 1390. In a preferred embodiment, the non hardenable fluidic material 1381 is then pumped into the interior region 1370 causing the interior region 1370 to pressurize. Once the interior region 1370 becomes sufficiently pressurized, the tubular member 1310 is extruded off of the expandable mandrel 1305. During the extrusion process, the expandable mandrel 1305 is raised out of the expanded portion of the tubular member 1310 by the support member 1345.

The wiper dart 1395 is preferably placed into the fluid passage 1320 by introducing the wiper dart 1395 into the fluid passage 1320 at a surface location in a conventional manner. The wiper dart 1395 may comprise any number of conventional commercially available devices from plugging a fluid passage such as, for example, Multiple Stage Cementer latch-down plugs, Omega latch-down plugs or three wiper latch-down plug/dart modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the wiper dart 1395 comprises a three wiper latch-down plug modified to latch and seal in the Multiple Stage

Cementer latch down plug 1350. The three wiper latch-down plug is available from Halliburton Energy Services in Dallas, TX.

After blocking the fluid passage 1330 using the wiper plug 1330 and wiper dart 1395, the non hardenable fluidic material 1381 may be pumped into the  
5 interior region 1370 at pressures and flow rates ranging, for example, from approximately 0 to 5000 psi and 0 to 1,500 gallons/min in order to optimally extrude the tubular member 1310 off of the mandrel 1305. In this manner, the amount of hardenable fluidic material within the interior of the tubular member 1310 is minimized.

10 In a preferred embodiment, after blocking the fluid passage 1330, the non hardenable fluidic material 1381 is preferably pumped into the interior region 1370 at pressures and flow rates ranging from approximately 500 to 9,000 psi and 40 to 3,000 gallons/min in order to optimally provide operating pressures to  
15 maintain the expansion process at rates sufficient to permit adjustments to be made in operating parameters during the extrusion process.

For typical tubular members 1310, the extrusion of the tubular member 1310 off of the expandable mandrel 1305 will begin when the pressure of the interior region 1370 reaches, for example, approximately 500 to 9,000 psi. In a preferred embodiment, the extrusion of the tubular member 1310 off of the  
20 expandable mandrel 1305 is a function of the tubular member diameter, wall thickness of the tubular member, geometry of the mandrel, the type of lubricant, the composition of the shoe and tubular member, and the yield strength of the tubular member. The optimum flow rate and operating pressures are preferably determined using conventional empirical methods.

25 During the extrusion process, the expandable mandrel 1305 may be raised out of the expanded portion of the tubular member 1310 at rates ranging, for example, from about 0 to 5 ft/sec. In a preferred embodiment, during the extrusion process, the expandable mandrel 1305 may be raised out of the expanded portion of the tubular member 1310 at rates ranging from about 0 to 2 ft/sec in order to  
30 optimally provide an efficient process, optimally permit operator adjustment of operation parameters, and ensure optimal completion of the extrusion process before curing of the material 1380.

When the upper end portion 1355 of the tubular member 1310 is extruded off of the expandable mandrel 1305, the outer surface of the upper end portion 1355 of the tubular member 1310 will preferably contact the interior surface of the lower end portion of the casing 1215 to form an fluid tight overlapping joint. The contact pressure of the overlapping joint may range, for example, from approximately 50 to 20,000 psi. In a preferred embodiment, the contact pressure of the overlapping joint ranges from approximately 400 to 10,000 psi in order to optimally provide contact pressure sufficient to ensure annular sealing and provide enough resistance to withstand typical tensile and compressive loads. In a particularly preferred embodiment, the sealing members 1340 will ensure an adequate fluidic and gaseous seal in the overlapping joint.

In a preferred embodiment, the operating pressure and flow rate of the non hardenable fluidic material 1381 is controllably ramped down when the expandable mandrel 1305 reaches the upper end portion 1355 of the tubular member 1310. In this manner, the sudden release of pressure caused by the complete extrusion of the tubular member 1310 off of the expandable mandrel 1305 can be minimized. In a preferred embodiment, the operating pressure is reduced in a substantially linear fashion from 100% to about 10% during the end of the extrusion process beginning when the mandrel 1305 has completed approximately all but about 5 feet of the extrusion process.

Alternatively, or in combination, a shock absorber is provided in the support member 1345 in order to absorb the shock caused by the sudden release of pressure.

Alternatively, or in combination, a mandrel catching structure is provided in the upper end portion 1355 of the tubular member 1310 in order to catch or at least decelerate the mandrel 1305.

Once the extrusion process is completed, the expandable mandrel 1305 is removed from the wellbore 1200. In a preferred embodiment, either before or after the removal of the expandable mandrel 1305, the integrity of the fluidic seal of the overlapping joint between the upper portion 1355 of the tubular member 1310 and the lower portion of the casing 1215 is tested using conventional methods. If the fluidic seal of the overlapping joint between the upper portion 1355 of the tubular

member 1310 and the lower portion of the casing 1215 is satisfactory, then the uncured portion of the material 1380 within the expanded tubular member 1310 is then removed in a conventional manner. The material 1380 within the annular region 1390 is then allowed to cure.

5 As illustrated in Fig. 11f, preferably any remaining cured material 1380 within the interior of the expanded tubular member 1310 is then removed in a conventional manner using a conventional drill string. The resulting new section of casing 1400 includes the expanded tubular member 1310 and an outer annular layer 1405 of cured material 305. The bottom portion of the apparatus 1300  
10 comprising the shoe 1315 may then be removed by drilling out the shoe 1315 using conventional drilling methods.

Referring now to Figs. 12 and 13, a preferred embodiment of a wellhead system 1500 formed using one or more of the apparatus and processes described above with reference to Figs. 1-11f will be described. The wellhead system 1500  
15 preferably includes a conventional Christmas tree/drilling spool assembly 1505, a thick wall casing 1510, an annular body of cement 1515, an outer casing 1520, an annular body of cement 1525, an intermediate casing 1530, and an inner casing 1535.

The Christmas tree/drilling spool assembly 1505 may comprise any number  
20 of conventional Christmas tree/drilling spool assemblies such as, for example, the SS-15 Subsea Wellhead System, Spool Tree Subsea Production System or the Compact Wellhead System available from suppliers such as Dril-Quip, Cameron or Breda, modified in accordance with the teachings of the present disclosure. The drilling spool assembly 1505 is preferably operably coupled to the thick wall casing  
25 1510 and/or the outer casing 1520. The assembly 1505 may be coupled to the thick wall casing 1510 and/or outer casing 1520, for example, by welding, a threaded connection or made from single stock. In a preferred embodiment, the assembly 1505 is coupled to the thick wall casing 1510 and/or outer casing 1520 by welding.

The thick wall casing 1510 is positioned in the upper end of a wellbore 1540.  
30 In a preferred embodiment, at least a portion of the thick wall casing 1510 extends above the surface 1545 in order to optimally provide easy access and attachment to the Christmas tree/drilling spool assembly 1505. The thick wall casing 1510 is

preferably coupled to the Christmas tree/drilling spool assembly 1505, the annular body of cement 1515, and the outer casing 1520.

The thick wall casing 1510 may comprise any number of conventional commercially available high strength wellbore casings such as, for example, Oilfield Country Tubular Goods, titanium tubing or stainless steel tubing. In a preferred embodiment, the thick wall casing 1510 comprises Oilfield Country Tubular Goods available from various foreign and domestic steel mills. In a preferred embodiment, the thick wall casing 1510 has a yield strength of about 40,000 to 135,000 psi in order to optimally provide maximum burst, collapse, and tensile strengths. In a preferred embodiment, the thick wall casing 1510 has a failure strength in excess of about 5,000 to 20,000 psi in order to optimally provide maximum operating capacity and resistance to degradation of capacity after being drilled through for an extended time period.

The annular body of cement 1515 provides support for the thick wall casing 1510. The annular body of cement 1515 may be provided using any number of conventional processes for forming an annular body of cement in a wellbore. The annular body of cement 1515 may comprise any number of conventional cement mixtures.

The outer casing 1520 is coupled to the thick wall casing 1510. The outer casing 1520 may be fabricated from any number of conventional commercially available tubular members modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the outer casing 1520 comprises any one of the expandable tubular members described above with reference to Figs. 1-11f.

In a preferred embodiment, the outer casing 1520 is coupled to the thick wall casing 1510 by expanding the outer casing 1520 into contact with at least a portion of the interior surface of the thick wall casing 1510 using any one of the embodiments of the processes and apparatus described above with reference to Figs. 1-11f. In an alternative embodiment, substantially all of the overlap of the outer casing 1520 with the thick wall casing 1510 contacts with the interior surface of the thick wall casing 1510.



The contact pressure of the interface between the outer casing 1520 and the thick wall casing 1510 may range, for example, from about 500 to 10,000 psi. In a preferred embodiment, the contact pressure between the outer casing 1520 and the thick wall casing 1510 ranges from about 500 to 10,000 psi in order to  
5 optimally activate the pressure activated sealing members and to ensure that the overlapping joint will optimally withstand typical extremes of tensile and compressive loads that are experienced during drilling and production operations.

As illustrated in Fig. 13, in a particularly preferred embodiment, the upper end of the outer casing 1520 includes one or more sealing members 1550 that  
10 provide a gaseous and fluidic seal between the expanded outer casing 1520 and the interior wall of the thick wall casing 1510. The sealing members 1550 may comprise any number of conventional commercially available seals such as, for example, lead, plastic, rubber, Teflon or epoxy, modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the sealing  
15 members 1550 comprise seals molded from StrataLock epoxy available from Halliburton Energy Services in order to optimally provide an hydraulic seal and a load bearing interference fit between the tubular members. In a preferred embodiment, the contact pressure of the interface between the thick wall casing 1510 and the outer casing 1520 ranges from about 500 to 10,000 psi in order to  
20 optimally activate the sealing members 1550 and also optimally ensure that the joint will withstand the typical operating extremes of tensile and compressive loads during drilling and production operations.

In an alternative preferred embodiment, the outer casing 1520 and the thick walled casing 1510 are combined in one unitary member.

25 The annular body of cement 1525 provides support for the outer casing 1520. In a preferred embodiment, the annular body of cement 1525 is provided using any one of the embodiments of the apparatus and processes described above with reference to Figs. 1-11f.

The intermediate casing 1530 may be coupled to the outer casing 1520 or  
30 the thick wall casing 1510. In a preferred embodiment, the intermediate casing 1530 is coupled to the thick wall casing 1510. The intermediate casing 1530 may

be fabricated from any number of conventional commercially available tubular members modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the intermediate casing 1530 comprises any one of the expandable tubular members described above with reference to Figs. 1-11f.

5 In a preferred embodiment, the intermediate casing 1530 is coupled to the thick wall casing 1510 by expanding at least a portion of the intermediate casing 1530 into contact with the interior surface of the thick wall casing 1510 using any one of the processes and apparatus described above with reference to Figs. 1-11f. In an alternative preferred embodiment, the entire length of the overlap of the  
10 intermediate casing 1530 with the thick wall casing 1510 contacts the inner surface of the thick wall casing 1510. The contact pressure of the interface between the intermediate casing 1530 and the thick wall casing 1510 may range, for example from about 500 to 10,000 psi. In a preferred embodiment, the contact pressure between the intermediate casing 1530 and the thick wall casing 1510  
15 ranges from about 500 to 10,000 psi in order to optimally activate the pressure activated sealing members and to optimally ensure that the joint will withstand typical operating extremes of tensile and compressive loads experienced during drilling and production operations.

As illustrated in Fig. 13, in a particularly preferred embodiment, the upper  
20 end of the intermediate casing 1530 includes one or more sealing members 1560 that provide a gaseous and fluidic seal between the expanded end of the intermediate casing 1530 and the interior wall of the thick wall casing 1510. The sealing members 1560 may comprise any number of conventional commercially available seals such as, for example, plastic, lead, rubber, Teflon or epoxy, modified  
25 in accordance with the teachings of the present disclosure. In a preferred embodiment, the sealing members 1560 comprise seals molded from StrataLock epoxy available from Halliburton Energy Services in order to optimally provide a hydraulic seal and a load bearing interference fit between the tubular members.

In a preferred embodiment, the contact pressure of the interface between  
30 the expanded end of the intermediate casing 1530 and the thick wall casing 1510 ranges from about 500 to 10,000 psi in order to optimally activate the sealing

members 1560 and also optimally ensure that the joint will withstand typical operating extremes of tensile and compressive loads that are experienced during drilling and production operations.

The inner casing 1535 may be coupled to the outer casing 1520 or the thick wall casing 1510. In a preferred embodiment, the inner casing 1535 is coupled to the thick wall casing 1510. The inner casing 1535 may be fabricated from any number of conventional commercially available tubular members modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the inner casing 1535 comprises any one of the expandable tubular members described above with reference to Figs. 1-11f.

In a preferred embodiment, the inner casing 1535 is coupled to the outer casing 1520 by expanding at least a portion of the inner casing 1535 into contact with the interior surface of the thick wall casing 1510 using any one of the processes and apparatus described above with reference to Figs. 1-11f. In an alternative preferred embodiment, the entire length of the overlap of the inner casing 1535 with the thick wall casing 1510 and intermediate casing 1530 contacts the inner surfaces of the thick wall casing 1510 and intermediate casing 1530. The contact pressure of the interface between the inner casing 1535 and the thick wall casing 1510 may range, for example from about 500 to 10,000 psi. In a preferred embodiment, the contact pressure between the inner casing 1535 and the thick wall casing 1510 ranges from about 500 to 10,000 psi in order to optimally activate the pressure activated sealing members and to ensure that the joint will withstand typical extremes of tensile and compressive loads that are commonly experienced during drilling and production operations.

As illustrated in Fig. 13, in a particularly preferred embodiment, the upper end of the inner casing 1535 includes one or more sealing members 1570 that provide a gaseous and fluidic seal between the expanded end of the inner casing 1535 and the interior wall of the thick wall casing 1510. The sealing members 1570 may comprise any number of conventional commercially available seals such as, for example, lead, plastic, rubber, Teflon or epoxy, modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the sealing members 1570 comprise seals molded from StrataLock epoxy available from

Halliburton Energy Services in order to optimally provide an hydraulic seal and a load bearing interference fit. In a preferred embodiment, the contact pressure of the interface between the expanded end of the inner casing 1535 and the thick wall casing 1510 ranges from about 500 to 10,000 psi in order to optimally activate  
5 the sealing members 1570 and also to optimally ensure that the joint will withstand typical operating extremes of tensile and compressive loads that are experienced during drilling and production operations.

In an alternative embodiment, the inner casings, 1520, 1530 and 1535, may be coupled to a previously positioned tubular member that is in turn coupled to the  
10 outer casing 1510. More generally, the present preferred embodiments may be used to form a concentric arrangement of tubular members.

Referring now to Figures 14a, 14b, 14c, 14d, 14e and 14f, a preferred embodiment of a method and apparatus for forming a mono-diameter well casing within a subterranean formation will now be described.

15 As illustrated in Fig. 14a, a wellbore 1600 is positioned in a subterranean formation 1605. A first section of casing 1610 is formed in the wellbore 1600. The first section of casing 1610 includes an annular outer body of cement 1615 and a tubular section of casing 1620. The first section of casing 1610 may be formed in the wellbore 1600 using conventional methods and apparatus. In a preferred  
20 embodiment, the first section of casing 1610 is formed using one or more of the methods and apparatus described above with reference to Figs. 1-13 or below with reference to Figs. 14b-17b.

The annular body of cement 1615 may comprise any number of conventional commercially available cement, or other load bearing, compositions. Alternatively,  
25 the body of cement 1615 may be omitted or replaced with an epoxy mixture.

The tubular section of casing 1620 preferably includes an upper end 1625 and a lower end 1630. Preferably, the lower end 1625 of the tubular section of casing 1620 includes an outer annular recess 1635 extending from the lower end 1630 of the tubular section of casing 1620. In this manner, the lower end 1625 of  
30 the tubular section of casing 1620 includes a thin walled section 1640. In a preferred embodiment, an annular body 1645 of a compressible material is coupled to and at least partially positioned within the outer annular recess 1635. In this

manner, the body of compressible material 1645 surrounds at least a portion of the thin walled section 1640.

The tubular section of casing 1620 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, stainless steel, automotive grade steel, carbon steel, low alloy steel, fiberglass or plastics. In a preferred embodiment, the tubular section of casing 1620 is fabricated from oilfield country tubular goods available from various foreign and domestic steel mills. The wall thickness of the thin walled section 1640 may range from about 0.125 to 1.5 inches. In a preferred embodiment, the wall thickness of the thin walled section 1640 ranges from 0.25 to 1.0 inches in order to optimally provide burst strength for typical operational conditions while also minimizing resistance to radial expansion. The axial length of the thin walled section 1640 may range from about 120 to 2400 inches. In a preferred embodiment, the axial length of the thin walled section 1640 ranges from about 240 to 480 inches.

The annular body of compressible material 1645 helps to minimize the radial force required to expand the tubular casing 1620 in the overlap with the tubular member 1715, helps to create a fluidic seal in the overlap with the tubular member 1715, and helps to create an interference fit sufficient to permit the tubular member 1715 to be supported by the tubular casing 1620. The annular body of compressible material 1645 may comprise any number of commercially available compressible materials such as, for example, epoxy, rubber, Teflon, plastics or lead tubes. In a preferred embodiment, the annular body of compressible material 1645 comprises StrataLock epoxy available from Halliburton Energy Services in order to optimally provide an hydraulic seal in the overlapped joint while also having compliance to thereby minimize the radial force required to expand the tubular casing. The wall thickness of the annular body of compressible material 1645 may range from about 0.05 to 0.75 inches. In a preferred embodiment, the wall thickness of the annular body of compressible material 1645 ranges from about 0.1 to 0.5 inches in order to optimally provide a large compressible zone, minimize the radial forces required to expand the tubular

casing, provide thickness for casing strings to provide contact with the inner surface of the wellbore upon radial expansion, and provide an hydraulic seal.

As illustrated in Fig. 14b, in order to extend the wellbore 1600 into the subterranean formation 1605, a drill string is used in a well known manner to drill  
5 out material from the subterranean formation 1605 to form a new wellbore section 1650. The diameter of the new section 1650 is preferably equal to or greater than the inner diameter of the tubular section of casing 1620.

As illustrated in Fig. 14c, a preferred embodiment of an apparatus 1700 for forming a mono-diameter wellbore casing in a subterranean formation is then  
10 positioned in the new section 1650 of the wellbore 1600. The apparatus 1700 preferably includes a support member 1705, an expandable mandrel or pig 1710, a tubular member 1715, a shoe 1720, slips 1725, a fluid passage 1730, one or more fluid passages 1735, a fluid passage 1740, a first compressible annular body 1745,  
a second compressible annular body 1750, and a pressure chamber 1755.

15 The support member 1705 supports the apparatus 1700 within the wellbore 1600. The support member 1705 is coupled to the mandrel 1710, the tubular member 1715, the shoe 1720, and the slips 1725. The support member 1075 preferably comprises a substantially hollow tubular member. The fluid passage 1730 is positioned within the support member 1705. The fluid passages 1735  
20 fluidicly couple the fluid passage 1730 with the pressure chamber 1755. The fluid passage 1740 fluidicly couples the fluid passage 1730 with the region outside of the apparatus 1700.

The support member 1705 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield  
25 country tubular goods, stainless steel, low alloy steel, carbon steel, 13 chromium steel, fiberglass, or other high strength materials. In a preferred embodiment, the support member 1705 is fabricated from oilfield country tubular goods available from various foreign and domestic steel mills in order to optimally provide operational strength and facilitate the use of other standard oil exploration  
30 handling equipment. In a preferred embodiment, at least a portion of the support member 1705 comprises coiled tubing or a drill pipe. In a particularly preferred

WO 01/04535

PCT/US00/18635

embodiment, the support member 1705 includes a load shoulder 1820 for supporting the mandrel 1710 when the pressure chamber 1755 is unpressurized.

The mandrel 1710 is supported by and slidingly coupled to the support member 1705 and the shoe 1720. The mandrel 1710 preferably includes an upper  
5 portion 1760 and a lower portion 1765. Preferably, the upper portion 1760 of the mandrel 1710 and the support member 1705 together define the pressure chamber 1755. Preferably, the lower portion 1765 of the mandrel 1710 includes an expansion member 1770 for radially expanding the tubular member 1715.

In a preferred embodiment, the upper portion 1760 of the mandrel 1710  
10 includes a tubular member 1775 having an inner diameter greater than an outer diameter of the support member 1705. In this manner, an annular pressure chamber 1755 is defined by and positioned between the tubular member 1775 and the support member 1705. The top 1780 of the tubular member 1775 preferably  
15 includes a bearing and a seal for sealing and supporting the top 1780 of the tubular member 1775 against the outer surface of the support member 1705. The bottom 1785 of the tubular member 1775 preferably includes a bearing and seal for sealing and supporting the bottom 1785 of the tubular member 1775 against the outer surface of the support member 1705 or shoe 1720. In this manner, the mandrel 1710 moves in an axial direction upon the pressurization of the pressure chamber  
20 1755.

The lower portion 1765 of the mandrel 1710 preferably includes an expansion member 1770 for radially expanding the tubular member 1715 during the pressurization of the pressure chamber 1755. In a preferred embodiment, the expansion member is expandable in the radial direction. In a preferred  
25 embodiment, the inner surface of the lower portion 1765 of the mandrel 1710 mates with and slides with respect to the outer surface of the shoe 1720. The outer diameter of the expansion member 1770 may range from about 90 to 100 % of the inner diameter of the tubular casing 1620. In a preferred embodiment, the outer diameter of the expansion member 1770 ranges from about 95 to 99 % of the inner  
30 diameter of the tubular casing 1620. The expansion member 1770 may be fabricated from any number of conventional commercially available materials such as, for example, machine tool steel, ceramics, tungsten carbide, titanium or other

WO 01/04535

PCT/US00/18635

high strength alloys. In a preferred embodiment, the expansion member 1770 is fabricated from D2 machine tool steel in order to optimally provide high strength and abrasion resistance.

5 The tubular member 1715 is coupled to and supported by the support member 1705 and slips 1725. The tubular member 1715 includes an upper portion 1790 and a lower portion 1795.

10 The upper portion 1790 of the tubular member 1715 preferably includes an inner annular recess 1800 that extends from the upper portion 1790 of the tubular member 1715. In this manner, at least a portion of the upper portion 1790 of the tubular member 1715 includes a thin walled section 1805. The first compressible annular member 1745 is preferably coupled to and supported by the outer surface of the upper portion 1790 of the tubular member 1715 in opposing relation to the thin wall section 1805.

15 The lower portion 1795 of the tubular member 1715 preferably includes an outer annular recess 1810 that extends from the lower portion 1790 of the tubular member 1715. In this manner, at least a portion of the lower portion 1795 of the tubular member 1715 includes a thin walled section 1815. The second compressible annular member 1750 is coupled to and at least partially supported within the outer annular recess 1810 of the upper portion 1790 of the tubular member 1715 in opposing relation to the thin wall section 1815.

20 The tubular member 1715 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, stainless steel, low alloy steel, carbon steel, automotive grade steel, fiberglass, 13 chrome steel, other high strength material, or high strength plastics. In a preferred embodiment, the tubular member 1715 is fabricated from oilfield country tubular goods available from various foreign and domestic steel mills in order to optimally provide operational strength.

25 The shoe 1720 is supported by and coupled to the support member 1705. The shoe 1720 preferably comprises a substantially hollow tubular member. In a preferred embodiment, the wall thickness of the shoe 1720 is greater than the wall thickness of the support member 1705 in order to optimally provide increased radial support to the mandrel 1710. The shoe 1720 may be fabricated from any



WO 01/04535

PCT/US00/18635

number of conventional commercially available materials such as, for example, oilfield country tubular goods, stainless steel, automotive grade steel, low alloy steel, carbon steel, or high strength plastics. In a preferred embodiment, the shoe 1720 is fabricated from oilfield country tubular goods available from various  
5 foreign and domestic steel mills in order to optimally provide matching operational strength throughout the apparatus.

The slips 1725 are coupled to and supported by the support member 1705. The slips 1725 removably support the tubular member 1715. In this manner, during the radial expansion of the tubular member 1715, the slips 1725 help to  
10 maintain the tubular member 1715 in a substantially stationary position by preventing upward movement of the tubular member 1715.

The slips 1725 may comprise any number of conventional commercially available slips such as, for example, RTTS packer tungsten carbide mechanical slips, RTTS packer wicker type mechanical slips, or Model 3L retrievable bridge  
15 plug tungsten carbide upper mechanical slips. In a preferred embodiment, the slips 1725 comprise RTTS packer tungsten carbide mechanical slips available from Halliburton Energy Services. In a preferred embodiment, the slips 1725 are adapted to support axial forces ranging from about 0 to 750,000 lbf.

The fluid passage 1730 conveys fluidic materials from a surface location into  
20 the interior of the support member 1705, the pressure chamber 1755, and the region exterior of the apparatus 1700. The fluid passage 1730 is fluidically coupled to the pressure chamber 1755 by the fluid passages 1735. The fluid passage 1730 is fluidically coupled to the region exterior to the apparatus 1700 by the fluid passage 1740.

25 In a preferred embodiment, the fluid passage 1730 is adapted to convey fluidic materials such as, for example, cement, epoxy, drilling muds, slag mix, water or drilling gasses. In a preferred embodiment, the fluid passage 1730 is adapted to convey fluidic materials at flow rate and pressures ranging from about 0 to 3,000 gallons/minute and 0 to 9,000 psi. in order to optimally provide flow  
30 rates and operational pressures for the radial expansion processes.

The fluid passages 1735 convey fluidic material from the fluid passage 1730 to the pressure chamber 1755. In a preferred embodiment, the fluid passage 1735

is adapted to convey fluidic materials such as, for example, cement, epoxy, drilling muds, water or drilling gasses. In a preferred embodiment, the fluid passage 1735 is adapted to convey fluidic materials at flow rate and pressures ranging from about 0 to 500 gallons/minute and 0 to 9,000 psi. in order to optimally provide  
5 operating pressures and flow rates for the various expansion processes.

The fluid passage 1740 conveys fluidic materials from the fluid passage 1730 to the region exterior to the apparatus 1700. In a preferred embodiment, the fluid passage 1740 is adapted to convey fluidic materials such as, for example, cement, epoxy, drilling muds, water or drilling gasses. In a preferred embodiment, the fluid  
10 passage 1740 is adapted to convey fluidic materials at flow rate and pressures ranging from about 0 to 3,000 gallons/minute and 0 to 9,000 psi. in order to optimally provide operating pressures and flow rates for the various radial expansion processes.

In a preferred embodiment, the fluid passage 1740 is adapted to receive a  
15 plug or other similar device for sealing the fluid passage 1740. In this manner, the pressure chamber 1755 may be pressurized.

The first compressible annular body 1745 is coupled to and supported by an exterior surface of the upper portion 1790 of the tubular member 1715. In a preferred embodiment, the first compressible annular body 1745 is positioned in  
20 opposing relation to the thin walled section 1805 of the tubular member 1715.

The first compressible annular body 1745 helps to minimize the radial force required to expand the tubular member 1715 in the overlap with the tubular casing 1620, helps to create a fluidic seal in the overlap with the tubular casing 1620, and helps to create an interference fit sufficient to permit the tubular  
25 member 1715 to be supported by the tubular casing 1620. The first compressible annular body 1745 may comprise any number of commercially available compressible materials such as, for example, epoxy, rubber, Teflon, plastics, or hollow lead tubes. In a preferred embodiment, the first compressible annular body 1745 comprises StrataLock epoxy available from Halliburton Energy Services in  
30 order to optimally provide an hydraulic seal, and compressibility to minimize the radial expansion force.

The wall thickness of the first compressible annular body 1745 may range from about 0.05 to 0.75 inches. In a preferred embodiment, the wall thickness of the first compressible annular body 1745 ranges from about 0.1 to 0.5 inches in order to optimally (1) provide a large compressible zone, (2) minimize the required  
5 radial expansion force, (3) transfer the radial force to the tubular casings. As a result, in a preferred embodiment, overall the outer diameter of the tubular member 1715 is approximately equal to the overall inner diameter of the tubular member 1620.

The second compressible annular body 1750 is coupled to and at least  
10 partially supported within the outer annular recess 1810 of the tubular member 1715. In a preferred embodiment, the second compressible annular body 1750 is positioned in opposing relation to the thin walled section 1815 of the tubular member 1715.

The second compressible annular body 1750 helps to minimize the radial  
15 force required to expand the tubular member 1715 in the overlap with another tubular member, helps to create a fluidic seal in the overlap of the tubular member 1715 with another tubular member, and helps to create an interference fit sufficient to permit another tubular member to be supported by the tubular member 1715. The second compressible annular body 1750 may comprise any  
20 number of commercially available compressible materials such as, for example, epoxy, rubber, Teflon, plastics or hollow lead tubing. In a preferred embodiment, the first compressible annular body 1750 comprises StrataLock epoxy available from Halliburton Energy Services in order to optimally provide an hydraulic seal in the overlapped joint, and compressibility that minimizes the radial expansion  
25 force.

The wall thickness of the second compressible annular body 1750 may range from about 0.05 to 0.75 inches. In a preferred embodiment, the wall thickness of the second compressible annular body 1750 ranges from about 0.1 to 0.5 inches in order to optimally provide a large compressible zone, and minimize the radial force  
30 required to expand the tubular member 1715 during subsequent radial expansion operations.

In an alternative embodiment, the outside diameter of the second compressible annular body 1750 is adapted to provide a seal against the surrounding formation thereby eliminating the need for an outer annular body of cement.

5       The pressure chamber 1755 is fluidly coupled to the fluid passage 1730 by the fluid passages 1735. The pressure chamber 1755 is preferably adapted to receive fluidic materials such as, for example, drilling muds, water or drilling gases. In a preferred embodiment, the pressure chamber 1755 is adapted to receive fluidic materials at flow rate and pressures ranging from about 0 to 500  
10   gallons/minute and 0 to 9,000 psi. in order to optimally provide expansion pressure. In a preferred embodiment, during pressurization of the pressure chamber 1755, the operating pressure of the pressure chamber ranges from about 0 to 5,000 psi in order to optimally provide expansion pressure while minimizing the possibility of a catastrophic failure due to over pressurization.

15       As illustrated in Fig. 14d, the apparatus 1700 is preferably positioned in the wellbore 1600 with the tubular member 1715 positioned in an overlapping relationship with the tubular casing 1620. In a particularly preferred embodiment, the thin wall sections, 1640 and 1805, of the tubular casing 1620 and tubular member 1725 are positioned in opposing overlapping relation. In this manner, the  
20   radial expansion of the tubular member 1725 will compress the thin wall sections, 1640 and 1805, and annular compressible members, 1645 and 1745, into intimate contact.

After positioning of the apparatus 1700, a fluidic material 1825 is then pumped into the fluid passage 1730. The fluidic material 1825 may comprise any  
25   number of conventional commercially available materials such as, for example, water, drilling mud, drilling gases, cement or epoxy. In a preferred embodiment, the fluidic material 1825 comprises a hardenable fluidic sealing material such as, for example, cement in order to provide an outer annular body around the expanded tubular member 1715.

30       The fluidic material 1825 may be pumped into the fluid passage 1730 at operating pressures and flow rates, for example, ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

WO 01/04535

PCT/US00/18635

The fluidic material 1825 pumped into the fluid passage 1730 passes through the fluid passage 1740 and outside of the apparatus 1700. The fluidic material 1825 fills the annular region 1830 between the outside of the apparatus 1700 and the interior walls of the wellbore 1600.

- 5        As illustrated in Fig. 14e, a plug 1835 is then introduced into the fluid passage 1730. The plug 1835 lodges in the inlet to the fluid passage 1740 fluidically isolating and blocking off the fluid passage 1730.

- 10        A fluidic material 1840 is then pumped into the fluid passage 1730. The fluidic material 1840 may comprise any number of conventional commercially available materials such as, for example, water, drilling mud or drilling gases. In a preferred embodiment, the fluidic material 1825 comprises a non-hardenable fluidic material such as, for example, drilling mud or drilling gases in order to optimally provide pressurization of the pressure chamber 1755:

- 15        The fluidic material 1840 may be pumped into the fluid passage 1730 at operating pressures and flow rates ranging, for example, from about 0 to 9,000 psi and 0 to 500 gallons/minute. In a preferred embodiment, the fluidic material 1840 is pumped into the fluid passage 1730 at operating pressures and flow rates ranging from about 500 to 5,000 psi and 0 to 500 gallons/minute in order to optimally provide operating pressures and flow rates for radial expansion.

- 20        The fluidic material 1840 pumped into the fluid passage 1730 passes through the fluid passages 1735 and into the pressure chamber 1755. Continued pumping of the fluidic material 1840 pressurizes the pressure chamber 1755. The pressurization of the pressure chamber 1755 causes the mandrel 1710 to move relative to the support member 1705 in the direction indicated by the arrows 1845.
- 25        In this manner, the mandrel 1710 will cause the tubular member 1715 to expand in the radial direction.

- 30        During the radial expansion process, the tubular member 1715 is prevented from moving in an upward direction by the slips 1725. A length of the tubular member 1715 is then expanded in the radial direction through the pressurization of the pressure chamber 1755. The length of the tubular member 1715 that is expanded during the expansion process will be proportional to the stroke length of the mandrel 1710. Upon the completion of a stroke, the operating pressure of

WO 01/04535

PCT/US00/18635

the pressure chamber 1755 is then reduced and the mandrel 1710 drops to its rest position with the tubular member 1715 supported by the mandrel 1715. The position of the support member 1705 may be adjusted throughout the radial expansion process in order to maintain the overlapping relationship between the thin walled sections, 1640 and 1805, of the tubular casing 1620 and tubular member 1715. The stroking of the mandrel 1710 is then repeated, as necessary, until the thin walled section 1805 of the tubular member 1715 is expanded into the thin walled section 1640 of the tubular casing 1620.

In a preferred embodiment, during the final stroke of the mandrel 1710, the slips 1725 are positioned as close as possible to the thin walled section 1805 of the tubular member 1715 in order to minimize slippage between the tubular member 1715 and tubular casing 1620 at the end of the radial expansion process. Alternatively, or in addition, the outside diameter of the first compressive annular member 1745 is selected to ensure sufficient interference fit with the tubular casing 1620 to prevent axial displacement of the tubular member 1715 during the final stroke. Alternatively, or in addition, the outside diameter of the second compressive annular body 1750 is large enough to provide an interference fit with the inside walls of the wellbore 1600 at an earlier point in the radial expansion process so as to prevent further axial displacement of the tubular member 1715.

In this final alternative, the interference fit is preferably selected to permit expansion of the tubular member 1715 by pulling the mandrel 1710 out of the wellbore 1600, without having to pressurize the pressure chamber 1755.

During the radial expansion process, the pressurized areas of the apparatus 1700 are limited to the fluid passages 1730 within the support member 1705 and the pressure chamber 1755 within the mandrel 1710. No fluid pressure acts directly on the tubular member 1715. This permits the use of operating pressures higher than the tubular member 1715 could normally withstand.

Once the tubular member 1715 has been completely expanded off of the mandrel 1710, the support member 1705 and mandrel 1710 are removed from the wellbore 1600. In a preferred embodiment, the contact pressure between the deformed thin wall sections, 1640 and 1805, and compressible annular members,

WO 01/04535

PCT/US00/18635

1645 and 1745, ranges from about 400 to 10,000 psi in order to optimally support the tubular member 1715 using the tubular casing 1620.

In this manner, the tubular member 1715 is radially expanded into contact with the tubular casing 1620 by pressurizing the interior of the fluid passage 1730  
5 and the pressure chamber 1755.

As illustrated in Fig. 14f, in a preferred embodiment, once the tubular member 1715 is completely expanded in the radial direction by the mandrel 1710, the support member 1705 and mandrel 1710 are removed from the wellbore 1600. In a preferred embodiment, the annular body of hardenable fluidic material is then  
10 allowed to cure to form a rigid outer annular body 1850. In the case where the tubular member 1715 is slotted, the hardenable fluidic material will preferably permeate and envelop the expanded tubular member 1715.

The resulting new section of wellbore casing 1855 includes the expanded tubular member 1715 and the rigid outer annular body 1850. The overlapping  
15 joint 1860 between the tubular casing 1620 and the expanded tubular member 1715 includes the deformed thin wall sections, 1640 and 1805, and the compressible annular bodies, 1645 and 1745. The inner diameter of the resulting combined wellbore casings is substantially constant. In this manner, a mono-diameter wellbore casing is formed. This process of expanding overlapping tubular  
20 members having thin wall end portions with compressible annular bodies into contact can be repeated for the entire length of a wellbore. In this manner, a mono-diameter wellbore casing can be provided for thousands of feet in a subterranean formation.

Referring now to Figures 15, 15a and 15b, an embodiment of an apparatus  
25 1900 for expanding a tubular member will be described. The apparatus 1900 preferably includes a drillpipe 1905, an innerstring adapter 1910, a sealing sleeve 1915, an inner sealing mandrel 1920, an upper sealing head 1925, a lower sealing head 1930, an outer sealing mandrel 1935, a load mandrel 1940, an expansion cone 1945, a mandrel launcher 1950, a mechanical slip body 1955, mechanical slips  
30 1960, drag blocks 1965, casing 1970, and fluid passages 1975, 1980, 1985, and 1990.

The drillpipe 1905 is coupled to the innerstring adapter 1910. During operation of the apparatus 1900, the drillpipe 1905 supports the apparatus 1900. The drillpipe 1905 preferably comprises a substantially hollow tubular member or members. The drillpipe 1905 may be fabricated from any number of conventional  
5 commercially available materials such as, for example, oilfield country tubular drillpipe, fiberglass or coiled tubing. In a preferred embodiment, the drillpipe 1905 is fabricated from coiled tubing in order to facilitate the placement of the apparatus 1900 in non-vertical wellbores. The drillpipe 1905 may be coupled to the innerstring adapter 1910 using any number of conventional commercially available  
10 mechanical couplings such as, for example, drillpipe connectors, OCTG specialty type box and pin connectors, a ratchet-latch type connector or a standard box by pin connector. In a preferred embodiment, the drillpipe 1905 is removably coupled to the innerstring adapter 1910 by a drillpipe connection.

The drillpipe 1905 preferably includes a fluid passage 1975 that is adapted  
15 to convey fluidic materials from a surface location into the fluid passage 1980. In a preferred embodiment, the fluid passage 1975 is adapted to convey fluidic materials such as, for example, cement, drilling mud, epoxy or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

20 The innerstring adapter 1910 is coupled to the drill string 1905 and the sealing sleeve 1915. The innerstring adapter 1910 preferably comprises a substantially hollow tubular member or members. The innerstring adapter 1910 may be fabricated from any number of conventional commercially available materials such as, for example, oil country tubular goods, low alloy steel, carbon  
25 steel, stainless steel or other high strength materials. In a preferred embodiment, the innerstring adapter 1910 is fabricated from oilfield country tubular goods in order to optimally provide mechanical properties that closely match those of the drill string 1905.

The innerstring adapter 1910 may be coupled to the drill string 1905 using  
30 any number of conventional commercially available mechanical couplings such as, for example, drillpipe connectors, oilfield country tubular goods specialty type threaded connectors, ratchet-latch type stab in connector, or a standard threaded



connection. In a preferred embodiment, the innerstring adapter 1910 is removably coupled to the drill pipe 1905 by a drillpipe connection. The innerstring adapter 1910 may be coupled to the sealing sleeve 1915 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe  
5 connection, oilfield country tubular goods specialty type threaded connector, ratchet-latch type stab in connectors, or a standard threaded connection. In a preferred embodiment, the innerstring adapter 1910 is removably coupled to the sealing sleeve 1915 by a standard threaded connection.

The innerstring adapter 1910 preferably includes a fluid passage 1980 that  
10 is adapted to convey fluidic materials from the fluid passage 1975 into the fluid passage 1985. In a preferred embodiment, the fluid passage 1980 is adapted to convey fluidic materials such as, for example, cement, drilling mud, epoxy, or lubricants at operating pressures and flow rates ranging from about 0 to 9,000-psi and 0 to 3,000 gallons/minute.

15 The sealing sleeve 1915 is coupled to the innerstring adapter 1910 and the inner sealing mandrel 1920. The sealing sleeve 1915 preferably comprises a substantially hollow tubular member or members. The sealing sleeve 1915 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, carbon steel, low alloy steel,  
20 stainless steel or other high strength materials. In a preferred embodiment, the sealing sleeve 1915 is fabricated from oilfield country tubular goods in order to optimally provide mechanical properties that substantially match the remaining components of the apparatus 1900.

The sealing sleeve 1915 may be coupled to the innerstring adapter 1910  
25 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type stab in connection, or a standard threaded connection. In a preferred embodiment, the sealing sleeve 1915 is removably coupled to the innerstring adapter 1910 by a standard threaded  
30 connection. The sealing sleeve 1915 may be coupled to the inner sealing mandrel 1920 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods

specialty type threaded connection, or a standard threaded connection. In a preferred embodiment, the sealing sleeve 1915 is removably coupled to the inner sealing mandrel 1920 by a standard threaded connection.

5 The sealing sleeve 1915 preferably includes a fluid passage 1985 that is adapted to convey fluidic materials from the fluid passage 1980 into the fluid passage 1990. In a preferred embodiment, the fluid passage 1985 is adapted to convey fluidic materials such as, for example, cement, drilling mud, epoxy or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

10 The inner sealing mandrel 1920 is coupled to the sealing sleeve 1915 and the lower sealing head 1930. The inner sealing mandrel 1920 preferably comprises a substantially hollow tubular member or members. The inner sealing mandrel 1920 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, stainless steel, low alloy steel, carbon steel or other similar high strength materials. In a preferred  
15 embodiment, the inner sealing mandrel 1920 is fabricated from stainless steel in order to optimally provide mechanical properties similar to the other components of the apparatus 1900 while also providing a smooth outer surface to support seals and other moving parts that can operate with minimal wear, corrosion and pitting.

20 The inner sealing mandrel 1920 may be coupled to the sealing sleeve 1915 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, or a standard threaded connection. In a preferred embodiment, the inner sealing mandrel 1920 is removably coupled to the sealing  
25 sleeve 1915 by a standard threaded connections. The inner sealing mandrel 1920 may be coupled to the lower sealing head 1930 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type stab in connectors or standard threaded connections. In a  
30 preferred embodiment, the inner sealing mandrel 1920 is removably coupled to the lower sealing head 1930 by a standard threaded connections connection.

The inner sealing mandrel 1920 preferably includes a fluid passage 1990 that is adapted to convey fluidic materials from the fluid passage 1985 into the fluid passage 1995. In a preferred embodiment, the fluid passage 1990 is adapted to convey fluidic materials such as, for example, cement, drilling mud, epoxy or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The upper sealing head 1925 is coupled to the outer sealing mandrel 1935 and the expansion cone 1945. The upper sealing head 1925 is also movably coupled to the outer surface of the inner sealing mandrel 1920 and the inner surface of the casing 1970. In this manner, the upper sealing head 1925, outer sealing mandrel 1935, and the expansion cone 1945 reciprocate in the axial direction. The radial clearance between the inner cylindrical surface of the upper sealing head 1925 and the outer surface of the inner sealing mandrel 1920 may range, for example, from about 0.025 to 0.05 inches. In a preferred embodiment, the radial clearance between the inner cylindrical surface of the upper sealing head 1925 and the outer surface of the inner sealing mandrel 1920 ranges from about 0.005 to 0.01 inches in order to optimally provide clearance for pressure seal placement. The radial clearance between the outer cylindrical surface of the upper sealing head 1925 and the inner surface of the casing 1970 may range, for example, from about 0.025 to 0.375 inches. In a preferred embodiment, the radial clearance between the outer cylindrical surface of the upper sealing head 1925 and the inner surface of the casing 1970 ranges from about 0.025 to 0.125 inches in order to optimally provide stabilization for the expansion cone 1945 as the expansion cone 1945 is upwardly moved inside the casing 1970.

The upper sealing head 1925 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The upper sealing head 1925 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, stainless steel, machine tool steel, or similar high strength materials. In a preferred embodiment, the upper sealing head 1925 is fabricated from stainless steel in order to optimally provide high strength and smooth outer surfaces that are resistant to wear, galling, corrosion and pitting.

The inner surface of the upper sealing head 1925 preferably includes one or more annular sealing members 2000 for sealing the interface between the upper sealing head 1925 and the inner sealing mandrel 1920. The sealing members 2000 may comprise any number of conventional commercially available annular sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2000 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial motion.

In a preferred embodiment, the upper sealing head 1925 includes a shoulder 2005 for supporting the upper sealing head 1925 on the lower sealing head 1930.

The upper sealing head 1925 may be coupled to the outer sealing mandrel 1935 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, or a standard threaded connections. In a preferred embodiment, the upper sealing head 1925 is removably coupled to the outer sealing mandrel 1935 by a standard threaded connections. In a preferred embodiment, the mechanical coupling between the upper sealing head 1925 and the outer sealing mandrel 1935 includes one or more sealing members 2010 for fluidically sealing the interface between the upper sealing head 1925 and the outer sealing mandrel 1935. The sealing members 2010 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2010 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroking motion.

The lower sealing head 1930 is coupled to the inner sealing mandrel 1920 and the load mandrel 1940. The lower sealing head 1930 is also movably coupled to the inner surface of the outer sealing mandrel 1935. In this manner, the upper sealing head 1925 and outer sealing mandrel 1935 reciprocate in the axial direction. The radial clearance between the outer surface of the lower sealing head 1930 and the inner surface of the outer sealing mandrel 1935 may range, for example, from about 0.025 to 0.05 inches. In a preferred embodiment, the radial

clearance between the outer surface of the lower sealing head 1930 and the inner surface of the outer sealing mandrel 1935 ranges from about 0.005 to 0.010 inches in order to optimally provide a close tolerance having room for the installation of pressure seal rings.

5        The lower sealing head 1930 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The lower sealing head 1930 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, stainless steel, machine tool steel or other similar high strength materials. In a preferred  
10        embodiment, the lower sealing head 1930 is fabricated from stainless steel in order to optimally provide high strength and resistance to wear, galling, corrosion, and pitting.

      The outer surface of the lower sealing head 1930 preferably includes one or more annular sealing members 2015 for sealing the interface between the lower  
15        sealing head 1930 and the outer sealing mandrel 1935. The sealing members 2015 may comprise any number of conventional commercially available annular sealing members such as, for example, o-rings, polypak seals, or metal spring energized seals. In a preferred embodiment, the sealing members 2015 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long  
20        axial stroke.

      The lower sealing head 1930 may be coupled to the inner sealing mandrel 1920 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, welding, amorphous bonding or a standard  
25        threaded connection. In a preferred embodiment, the lower sealing head 1930 is removably coupled to the inner sealing mandrel 1920 by a standard threaded connection.

      In a preferred embodiment, the mechanical coupling between the lower sealing head 1930 and the inner sealing mandrel 1920 includes one or more sealing  
30        members 2020 for fluidically sealing the interface between the lower sealing head 1930 and the inner sealing mandrel 1920. The sealing members 2020 may comprise any number of conventional commercially available sealing members

such as, for example, o-rings, polypak seals, or metal spring energized seals. In a preferred embodiment, the sealing members 2020 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial motion.

The lower sealing head 1930 may be coupled to the load mandrel 1940 using  
5 any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connections, welding, amorphous bonding or a standard threaded connection. In a preferred embodiment, the lower sealing head 1930 is removably coupled to the load mandrel 1940 by a standard threaded connection. In a  
10 preferred embodiment, the mechanical coupling between the lower sealing head 1930 and the load mandrel 1940 includes one or more sealing members 2025 for fluidically sealing the interface between the lower sealing head 1930 and the load mandrel 1940. The sealing members 2025 may comprise any number of conventional commercially available sealing members such as, for example, o-rings,  
15 polypak seals, or metal spring energized seals. In a preferred embodiment, the sealing members 2025 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

In a preferred embodiment, the lower sealing head 1930 includes a throat passage 2040 fluidically coupled between the fluid passages 1990 and 1995. The  
20 throat passage 2040 is preferably of reduced size and is adapted to receive and engage with a plug 2045, or other similar device. In this manner, the fluid passage 1990 is fluidically isolated from the fluid passage 1995. In this manner, the pressure chamber 2030 is pressurized.

The outer sealing mandrel 1935 is coupled to the upper sealing head 1925  
25 and the expansion cone 1945. The outer sealing mandrel 1935 is also movably coupled to the inner surface of the casing 1970 and the outer surface of the lower sealing head 1930. In this manner, the upper sealing head 1925, outer sealing mandrel 1935, and the expansion cone 1945 reciprocate in the axial direction. The radial clearance between the outer surface of the outer sealing mandrel 1935 and  
30 the inner surface of the casing 1970 may range, for example, from about 0.025 to 0.375 inches. In a preferred embodiment, the radial clearance between the outer surface of the outer sealing mandrel 1935 and the inner surface of the casing 1970

ranges from about 0.025 to 0.125 inches in order to optimally provide maximum piston surface area to maximize the radial expansion force. The radial clearance between the inner surface of the outer sealing mandrel 1935 and the outer surface of the lower sealing head 1930 may range, for example, from about 0.025 to 0.05 inches. In a preferred embodiment, the radial clearance between the inner surface of the outer sealing mandrel 1935 and the outer surface of the lower sealing head 1930 ranges from about 0.005 to 0.010 inches in order to optimally provide a minimum gap for the sealing elements to bridge and seal.

The outer sealing mandrel 1935 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The outer sealing mandrel 1935 may be fabricated from any number of conventional commercially available materials such as, for example, low alloy steel, carbon steel, 13 chromium steel or stainless steel. In a preferred embodiment, the outer sealing mandrel 1935 is fabricated from stainless steel in order to optimally provide maximum strength and minimum wall thickness while also providing resistance to corrosion, galling and pitting.

The outer sealing mandrel 1935 may be coupled to the upper sealing head 1925 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, standard threaded connections, or welding. In a preferred embodiment, the outer sealing mandrel 1935 is removably coupled to the upper sealing head 1925 by a standard threaded connections connection. The outer sealing mandrel 1935 may be coupled to the expansion cone 1945 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, or a standard threaded connections connection, or welding. In a preferred embodiment, the outer sealing mandrel 1935 is removably coupled to the expansion cone 1945 by a standard threaded connections connection.

The upper sealing head 1925, the lower sealing head 1930, the inner sealing mandrel 1920, and the outer sealing mandrel 1935 together define a pressure chamber 2030. The pressure chamber 2030 is fluidically coupled to the passage 1990 via one or more passages 2035. During operation of the apparatus 1900, the plug

2045 engages with the throat passage 2040 to fluidically isolate the fluid passage 1990 from the fluid passage 1995. The pressure chamber 2030 is then pressurized which in turn causes the upper sealing head 1925, outer sealing mandrel 1935, and expansion cone 1945 to reciprocate in the axial direction. The axial motion of the  
5 expansion cone 1945 in turn expands the casing 1970 in the radial direction.

The load mandrel 1940 is coupled to the lower sealing head 1930 and the mechanical slip body 1955. The load mandrel 1940 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The load mandrel 1940 may be fabricated from any number of conventional  
10 commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the load mandrel 1940 is fabricated from oilfield country tubular goods in order to optimally provide high strength.

The load mandrel 1940 may be coupled to the lower sealing head 1930 using  
15 any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, welding, amorphous bonding or a standard threaded connection. In a preferred embodiment, the load mandrel 1940 is removably coupled to the lower sealing head 1930 by a standard threaded connection. The  
20 load mandrel 1940 may be coupled to the mechanical slip body 1955 using any number of conventional commercially available mechanical couplings such as, for example, a drillpipe connection, oilfield country tubular goods specialty type threaded connections, welding, amorphous bonding, or a standard threaded connections connection. In a preferred embodiment, the load mandrel 1940 is  
25 removably coupled to the mechanical slip body 1955 by a standard threaded connections connection.

The load mandrel 1940 preferably includes a fluid passage 1995 that is adapted to convey fluidic materials from the fluid passage 1990 to the region outside of the apparatus 1900. In a preferred embodiment, the fluid passage 1995  
30 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud, or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.



WO 01/04535

PCT/US00/18635

The expansion cone 1945 is coupled to the outer sealing mandrel 1935. The expansion cone 1945 is also movably coupled to the inner surface of the casing 1970. In this manner, the upper sealing head 1925, outer sealing mandrel 1935, and the expansion cone 1945 reciprocate in the axial direction. The reciprocation  
5 of the expansion cone 1945 causes the casing 1970 to expand in the radial direction.

The expansion cone 1945 preferably comprises an annular member having substantially cylindrical inner and conical outer surfaces. The outside radius of the outside conical surface may range, for example, from about 2 to 34 inches. In  
10 a preferred embodiment, the outside radius of the outside conical surface ranges from about 3 to 28 inches in order to optimally provide cone dimensions for the typical range of tubular members.

The axial length of the expansion cone 1945 may range, for example, from about 2 to 8 times the largest outer diameter of the expansion cone 1945. In a  
15 preferred embodiment, the axial length of the expansion cone 1945 ranges from about 3 to 5 times the largest outer diameter of the expansion cone 1945 in order to optimally provide stability and centralization of the expansion cone 1945 during the expansion process. In a preferred embodiment, the angle of attack of the expansion cone 1945 ranges from about 5 to 30 degrees in order to optimally  
20 balance friction forces with the desired amount of radial expansion. The expansion cone 1945 angle of attack will vary as a function of the operating parameters of the particular expansion operation.

The expansion cone 1945 may be fabricated from any number of conventional commercially available materials such as, for example, machine tool  
25 steel, ceramics, tungsten carbide, nitride steel, or other similar high strength materials. In a preferred embodiment, the expansion cone 1945 is fabricated from D2 machine tool steel in order to optimally provide high strength and resistance to corrosion, wear, galling, and pitting. In a particularly preferred embodiment, the outside surface of the expansion cone 1945 has a surface hardness ranging  
30 from about 58 to 62 Rockwell C in order to optimally provide high strength and resist wear and galling.

WO 01/04535

PCT/US00/18635

The expansion cone 1945 may be coupled to the outside sealing mandrel 1935 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield tubular country goods specialty type threaded connection, welding, amorphous bonding, or a standard threaded connections connection. In a preferred embodiment, the expansion cone 1945 is coupled to the outside sealing mandrel 1935 using a standard threaded connections connection in order to optimally provide connector strength for the typical operating loading conditions while also permitting easy replacement of the expansion cone 1945.

10 The mandrel launcher 1950 is coupled to the casing 1970. The mandrel launcher 1950 comprises a tubular section of casing having a reduced wall thickness compared to the casing 1970. In a preferred embodiment, the wall thickness of the mandrel launcher is about 50 to 100-% of the wall thickness of the casing 1970. In this manner, the initiation of the radial expansion of the casing 1970 is facilitated, and the insertion of the larger outside diameter mandrel launcher 1950 into the wellbore and/or casing is facilitated.

The mandrel launcher 1950 may be coupled to the casing 1970 using any number of conventional mechanical couplings. The mandrel launcher 1950 may have a wall thickness ranging, for example, from about 0.15 to 1.5 inches. In a preferred embodiment, the wall thickness of the mandrel launcher 1950 ranges from about 0.25 to 0.75 inches in order to optimally provide high strength with a small overall profile. The mandrel launcher 1950 may be fabricated from any number of conventional commercially available materials such as, for example, oil field tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the mandrel launcher 1950 is fabricated from oil field tubular goods of higher strength but lower wall thickness than the casing 1970 in order to optimally provide a thin walled container with approximately the same burst strength as the casing 1970.

The mechanical slip body 1955 is coupled to the load mandrel 1970, the mechanical slips 1960, and the drag blocks 1965. The mechanical slip body 1955 preferably comprises a tubular member having an inner passage 2050 fluidically

WO 01/04535

PCT/US00/18635

coupled to the passage 1995. In this manner, fluidic materials may be conveyed from the passage 2050 to a region outside of the apparatus 1900.

The mechanical slip body 1955 may be coupled to the load mandrel 1940 using any number of conventional mechanical couplings. In a preferred embodiment, the mechanical slip body 1955 is removably coupled to the load mandrel 1940 using a standard threaded connection in order to optimally provide high strength and permit the mechanical slip body 1955 to be easily replaced. The mechanical slip body 1955 may be coupled to the mechanical slips 1955 using any number of conventional mechanical couplings. In a preferred embodiment, the mechanical slip body 1955 is removably coupled to the mechanical slips 1955 using threads and sliding steel retainer rings in order to optimally provide high strength coupling and also permit easy replacement of the mechanical slips 1955. The mechanical slip body 1955 may be coupled to the drag blocks 1965 using any number of conventional mechanical couplings. In a preferred embodiment, the mechanical slip body 1955 is removably coupled to the drag blocks 1965 using threaded connections and sliding steel retainer rings in order to optimally provide high strength and also permit easy replacement of the drag blocks 1965.

The mechanical slips 1960 are coupled to the outside surface of the mechanical slip body 1955. During operation of the apparatus 1900, the mechanical slips 1960 prevent upward movement of the casing 1970 and mandrel launcher 1950. In this manner, during the axial reciprocation of the expansion cone 1945, the casing 1970 and mandrel launcher 1950 are maintained in a substantially stationary position. In this manner, the mandrel launcher 1950 and casing 1970 are expanded in the radial direction by the axial movement of the expansion cone 1945.

The mechanical slips 1960 may comprise any number of conventional commercially available mechanical slips such as, for example, RTTS packer tungsten carbide mechanical slips, RTTS packer wicker type mechanical slips or Model 3L retrievable bridge plug tungsten carbide upper mechanical slips. In a preferred embodiment, the mechanical slips 1960 comprise RTTS packer tungsten carbide mechanical slips available from Halliburton Energy Services in order to

WO 01/04535

PCT/US00/18635

optimally provide resistance to axial movement of the casing 1970 during the expansion process.

The drag blocks 1965 are coupled to the outside surface of the mechanical slip body 1955. During operation of the apparatus 1900, the drag blocks 1965 prevent upward movement of the casing 1970 and mandrel launcher 1950. In this manner, during the axial reciprocation of the expansion cone 1945, the casing 1970 and mandrel launcher 1950 are maintained in a substantially stationary position. In this manner, the mandrel launcher 1950 and casing 1970 are expanded in the radial direction by the axial movement of the expansion cone 1945.

The drag blocks 1965 may comprise any number of conventional commercially available mechanical slips such as, for example, RTTS packer tungsten carbide mechanical slips, RTTS packer wicker type mechanical slips or Model 3L retrievable bridge plug tungsten carbide upper mechanical slips. In a preferred embodiment, the drag blocks 1965 comprise RTTS packer tungsten carbide mechanical slips available from Halliburton Energy Services in order to optimally provide resistance to axial movement of the casing 1970 during the expansion process.

The casing 1970 is coupled to the mandrel launcher 1950. The casing 1970 is further removably coupled to the mechanical slips 1960 and drag blocks 1965. The casing 1970 preferably comprises a tubular member. The casing 1970 may be fabricated from any number of conventional commercially available materials such as, for example, slotted tubulars, oil field country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the casing 1970 is fabricated from oilfield country tubular goods available from various foreign and domestic steel mills in order to optimally provide high strength. In a preferred embodiment, the upper end of the casing 1970 includes one or more sealing members positioned about the exterior of the casing 1970.

During operation, the apparatus 1900 is positioned in a wellbore with the upper end of the casing 1970 positioned in an overlapping relationship within an existing wellbore casing. In order minimize surge pressures within the borehole during placement of the apparatus 1900, the fluid passage 1975 is preferably

WO 01/04535

PCT/US00/18635

provided with one or more pressure relief passages. During the placement of the apparatus 1900 in the wellbore, the casing 1970 is supported by the expansion cone 1945.

After positioning of the apparatus 1900 within the bore hole in an overlapping relationship with an existing section of wellbore casing, a first fluidic material is pumped into the fluid passage 1975 from a surface location. The first fluidic material is conveyed from the fluid passage 1975 to the fluid passages 1980, 1985, 1990, 1995, and 2050. The first fluidic material will then exit the apparatus and fill the annular region between the outside of the apparatus 1900 and the interior walls of the bore hole.

The first fluidic material may comprise any number of conventional commercially available materials such as, for example, drilling mud, water, epoxy or cement. In a preferred embodiment, the first fluidic material comprises a hardenable fluidic sealing material such as, for example, cement or epoxy. In this manner, a wellbore casing having an outer annular layer of a hardenable material may be formed.

The first fluidic material may be pumped into the apparatus 1900 at operating pressures and flow rates ranging, for example, from about 0 to 4,500 psi, and 0 to 3,000 gallons/minute. In a preferred embodiment, the first fluidic material is pumped into the apparatus 1900 at operating pressures and flow rates ranging from about 0 to 4,500 psi and 0 to 3,000 gallons/minute in order to optimally provide operating pressures and flow rates for typical operating conditions.

At a predetermined point in the injection of the first fluidic material such as, for example, after the annular region outside of the apparatus 1900 has been filled to a predetermined level, a plug 2045, dart, or other similar device is introduced into the first fluidic material. The plug 2045 lodges in the throat passage 2040 thereby fluidically isolating the fluid passage 1990 from the fluid passage 1995.

After placement of the plug 2045 in the throat passage 2040, a second fluidic material is pumped into the fluid passage 1975 in order to pressurize the pressure chamber 2030. The second fluidic material may comprise any number of

conventional commercially available materials such as, for example, water, drilling gases, drilling mud or lubricant. In a preferred embodiment, the second fluidic material comprises a non-hardenable fluidic material such as, for example, water, drilling mud or lubricant in order minimize frictional forces.

5       The second fluidic material may be pumped into the apparatus 1900 at operating pressures and flow rates ranging, for example, from about 0 to 4,500 psi and 0 to 4,500 gallons/minute. In a preferred embodiment, the second fluidic material is pumped into the apparatus 1900 at operating pressures and flow rates ranging from about 0 to 3,500 psi, and 0 to 1,200 gallons/minute in order to  
10       optimally provide expansion of the casing 1970.

      The pressurization of the pressure chamber 2030 causes the upper sealing head 1925, outer sealing mandrel 1935, and expansion cone 1945 to move in an axial direction. As the expansion cone 1945 moves in the axial direction, the expansion cone 1945 pulls the mandrel launcher 1950 and drag blocks 1965 along,  
15       which sets the mechanical slips 1960 and stops further axial movement of the mandrel launcher 1950 and casing 1970. In this manner, the axial movement of the expansion cone 1945 radially expands the mandrel launcher 1950 and casing 1970.

      Once the upper sealing head 1925, outer sealing mandrel 1935, and  
20       expansion cone 1945 complete an axial stroke, the operating pressure of the second fluidic material is reduced and the drill string 1905 is raised. This causes the inner sealing mandrel 1920, lower sealing head 1930, load mandrel 1940, and mechanical slip body 1955 to move upward. This unsets the mechanical slips 1960 and permits the mechanical slips 1960 and drag blocks 1965 to be moved upward within the  
25       mandrel launcher and casing 1970. When the lower sealing head 1930 contacts the upper sealing head 1925, the second fluidic material is again pressurized and the radial expansion process continues. In this manner, the mandrel launcher 1950 and casing 1970 are radial expanded through repeated axial strokes of the upper sealing head 1925, outer sealing mandrel 1935 and expansion cone 1945.  
30       Throughput the radial expansion process, the upper end of the casing 1970 is preferably maintained in an overlapping relation with an existing section of wellbore casing.

WO 01/04535

PCT/US00/18635

At the end of the radial expansion process, the upper end of the casing 1970 is expanded into intimate contact with the inside surface of the lower end of the existing wellbore casing. In a preferred embodiment, the sealing members provided at the upper end of the casing 1970 provide a fluidic seal between the  
5 outside surface of the upper end of the casing 1970 and the inside surface of the lower end of the existing wellbore casing. In a preferred embodiment, the contact pressure between the casing 1970 and the existing section of wellbore casing ranges from about 400 to 10,000 psi in order to optimally provide contact pressure for activating sealing members, provide optimal resistance to axial movement of  
10 the expanded casing 1970, and optimally support typical tensile and compressive loads.

In a preferred embodiment, as the expansion cone 1945 nears the end of the casing 1970, the operating flow rate of the second fluidic material is reduced in order to minimize shock to the apparatus 1900. In an alternative embodiment, the  
15 apparatus 1900 includes a shock absorber for absorbing the shock created by the completion of the radial expansion of the casing 1970.

In a preferred embodiment, the reduced operating pressure of the second fluidic material ranges from about 100 to 1,000 psi as the expansion cone 1945 nears the end of the casing 1970 in order to optimally provide reduced axial  
20 movement and velocity of the expansion cone 1945. In a preferred embodiment, the operating pressure of the second fluidic material is reduced during the return stroke of the apparatus 1900 to the range of about 0 to 500 psi in order minimize the resistance to the movement of the expansion cone 1945. In a preferred embodiment, the stroke length of the apparatus 1900 ranges from about 10 to 45  
25 feet in order to optimally provide equipment lengths that can be handled by typical oil well rigging equipment while also minimizing the frequency at which the expansion cone 1945 must be stopped so the apparatus 1900 can be re-stroked for further expansion operations.

In an alternative embodiment, at least a portion of the upper sealing head  
30 1925 includes an expansion cone for radially expanding the mandrel launcher 1950 and casing 1970 during operation of the apparatus 1900 in order to increase the

WO 01/04535

PCT/US00/18635

surface area of the casing 1970 acted upon during the radial expansion process. In this manner, the operating pressures can be reduced.

In an alternative embodiment, mechanical slips are positioned in an axial location between the sealing sleeve 1915 and the inner sealing mandrel 1920 in order to simplify the operation and assembly of the apparatus 1900.

Upon the complete radial expansion of the casing 1970, if applicable, the first fluidic material is permitted to cure within the annular region between the outside of the expanded casing 1970 and the interior walls of the wellbore. In the case where the expanded casing 1970 is slotted, the cured fluidic material will preferably permeate and envelop the expanded casing. In this manner, a new section of wellbore casing is formed within a wellbore. Alternatively, the apparatus 1900 may be used to join a first section of pipeline to an existing section of pipeline. Alternatively, the apparatus 1900 may be used to directly line the interior of a wellbore with a casing, without the use of an outer annular layer of a hardenable material. Alternatively, the apparatus 1900 may be used to expand a tubular support member in a hole.

During the radial expansion process, the pressurized areas of the apparatus 1900 are limited to the fluid passages 1975, 1980, 1985, and 1990, and the pressure chamber 2030. No fluid pressure acts directly on the mandrel launcher 1950 and casing 1970. This permits the use of operating pressures higher than the mandrel launcher 1950 and casing 1970 could normally withstand.

Referring now to Figure 16, a preferred embodiment of an apparatus 2100 for forming a mono-diameter wellbore casing will be described. The apparatus 2100 preferably includes a drillpipe 2105, an innerstring adapter 2110, a sealing sleeve 2115, an inner sealing mandrel 2120, slips 2125, upper sealing head 2130, lower sealing head 2135, outer sealing mandrel 2140, load mandrel 2145, expansion cone 2150, and casing 2155.

The drillpipe 2105 is coupled to the innerstring adapter 2110. During operation of the apparatus 2100, the drillpipe 2105 supports the apparatus 2100. The drillpipe 2105 preferably comprises a substantially hollow tubular member or members. The drillpipe 2105 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular



WO 01/04535

PCT/US00/18635

goods, low alloy steel, carbon steel, stainless steel or other similar high strength material. In a preferred embodiment, the drillpipe 2105 is fabricated from coiled tubing in order to facilitate the placement of the apparatus 1900 in non-vertical wellbores. The drillpipe 2105 may be coupled to the innerstring adapter 2110

5 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type connection, or a standard threaded connection. In a preferred embodiment, the drillpipe 2105 is removably coupled to the innerstring adapter 2110 by a drill pipe connection.

10 The drillpipe 2105 preferably includes a fluid passage 2160 that is adapted to convey fluidic materials from a surface location into the fluid passage 2165. In a preferred embodiment, the fluid passage 2160 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to

15 3,000 gallons/minute.

The innerstring adapter 2110 is coupled to the drill string 2105 and the sealing sleeve 2115. The innerstring adapter 2110 preferably comprises a substantially hollow tubular member or members. The innerstring adapter 2110 may be fabricated from any number of conventional commercially available

20 materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the innerstring adapter 2110 is fabricated from stainless steel in order to optimally provide high strength, low friction, and resistance to corrosion and wear.

25 The innerstring adapter 2110 may be coupled to the drill string 2105 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type connection or a standard threaded connection. In a preferred embodiment, the innerstring adapter 2110 is removably

30 coupled to the drill pipe 2105 by a drillpipe connection. The innerstring adapter 2110 may be coupled to the sealing sleeve 2115 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe

connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection, or a standard threaded connection. In a preferred embodiment, the innerstring adapter 2110 is removably coupled to the sealing sleeve 2115 by a standard threaded connection.

- 5           The innerstring adapter 2110 preferably includes a fluid passage 2165 that is adapted to convey fluidic materials from the fluid passage 2160 into the fluid passage 2170. In a preferred embodiment, the fluid passage 2165 is adapted to convey fluidic materials such as, for example, cement, epoxy, water drilling muds, or lubricants at operating pressures and flow rates ranging from about 0 to 9,000  
10   psi and 0 to 3,000 gallons/minute.

- The sealing sleeve 2115 is coupled to the innerstring adapter 2110 and the inner sealing mandrel 2120. The sealing sleeve 2115 preferably comprises a substantially hollow tubular member or members. The sealing sleeve 2115 may  
15   be fabricated from any number of conventional commercially available materials such as, for example, oil field tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the sealing sleeve 2115 is fabricated from stainless steel in order to optimally provide high strength, low friction surfaces, and resistance to corrosion, wear, galling, and pitting.

- 20           The sealing sleeve 2115 may be coupled to the innerstring adapter 2110 using any number of conventional commercially available mechanical couplings such as, for example, a standard threaded connection, oilfield country tubular goods specialty type threaded connections, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the sealing sleeve 2115  
25   is removably coupled to the innerstring adapter 2110 by a standard threaded connection. The sealing sleeve 2115 may be coupled to the inner sealing mandrel 2120 using any number of conventional commercially available mechanical couplings such as, for example, a standard threaded connection, oilfield country tubular goods specialty type threaded connections, welding, amorphous bonding,  
30   or a standard threaded connection. In a preferred embodiment, the sealing sleeve 2115 is removably coupled to the inner sealing mandrel 2120 by a standard threaded connection.

WO 01/04535

PCT/US00/18635

The sealing sleeve 2115 preferably includes a fluid passage 2170 that is adapted to convey fluidic materials from the fluid passage 2165 into the fluid passage 2175. In a preferred embodiment, the fluid passage 2170 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud, or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The inner sealing mandrel 2120 is coupled to the sealing sleeve 2115, slips 2125, and the lower sealing head 2135. The inner sealing mandrel 2120 preferably comprises a substantially hollow tubular member or members. The inner sealing mandrel 2120 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the inner sealing mandrel 2120 is fabricated from stainless steel in order to optimally provide high strength, low friction surfaces, and corrosion and wear resistance.

The inner sealing mandrel 2120 may be coupled to the sealing sleeve 2115 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, or a standard threaded connection. In a preferred embodiment, the inner sealing mandrel 2120 is removably coupled to the sealing sleeve 2115 by a standard threaded connection. The standard threaded connection provides high strength and permits easy replacement of components. The inner sealing mandrel 2120 may be coupled to the slips 2125 using any number of conventional commercially available mechanical couplings such as, for example, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the inner sealing mandrel 2120 is removably coupled to the slips 2125 by a standard threaded connection. The inner sealing mandrel 2120 may be coupled to the lower sealing head 2135 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, welding, amorphous bonding or a standard threaded connection. In a preferred

embodiment, the inner sealing mandrel 2120 is removably coupled to the lower sealing head 2135 by a standard threaded connection.

The inner sealing mandrel 2120 preferably includes a fluid passage 2175 that is adapted to convey fluidic materials from the fluid passage 2170 into the fluid passage 2180. In a preferred embodiment, the fluid passage 2175 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The slips 2125 are coupled to the outer surface of the inner sealing mandrel 2120. During operation of the apparatus 2100, the slips 2125 preferably maintain the casing 2155 in a substantially stationary position during the radial expansion of the casing 2155. In a preferred embodiment, the slips 2125 are activated using the fluid passages 2185 to convey pressurized fluid material into the slips 2125.

The slips 2125 may comprise any number of commercially available hydraulic slips such as, for example, RTTS packer tungsten carbide hydraulic slips or Model 3L retrievable bridge plug hydraulic slips. In a preferred embodiment, the slips 2125 comprise RTTS packer tungsten carbide hydraulic slips available from Halliburton Energy Services in order to optimally provide resistance to axial movement of the casing 2155 during the expansion process. In a particularly preferred embodiment, the slips include a fluid passage 2190, pressure chamber 2195, spring return 2200, and slip member 2205.

The slips 2125 may be coupled to the inner sealing mandrel 2120 using any number of conventional mechanical couplings. In a preferred embodiment, the slips 2125 are removably coupled to the outer surface of the inner sealing mandrel 2120 by a thread connection in order to optimally provide interchangeability of parts.

The upper sealing head 2130 is coupled to the outer sealing mandrel 2140 and expansion cone 2150. The upper sealing head 2130 is also movably coupled to the outer surface of the inner sealing mandrel 2120 and the inner surface of the casing 2155. In this manner, the upper sealing head 2130 reciprocates in the axial direction. The radial clearance between the inner cylindrical surface of the upper sealing head 2130 and the outer surface of the inner sealing mandrel 2120 may

WO 01/04535

PCT/US00/18635

range, for example, from about 0.025 to 0.05 inches. In a preferred embodiment, the radial clearance between the inner cylindrical surface of the upper sealing head 2130 and the outer surface of the inner sealing mandrel 2120 ranges from about 0.005 to 0.010 inches in order to optimally provide a pressure seal. The radial  
5 clearance between the outer cylindrical surface of the upper sealing head 2130 and the inner surface of the casing 2155 may range, for example, from about 0.025 to 0.375 inches. In a preferred embodiment, the radial clearance between the outer cylindrical surface of the upper sealing head 2130 and the inner surface of the casing 2155 ranges from about 0.025 to 0.125 inches in order to optimally provide  
10 stabilization for the expansion cone 2130 during axial movement of the expansion cone 2130.

The upper sealing head 2130 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The upper sealing head 2130 may be fabricated from any number of conventional commercially available  
15 materials such as, for example, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the upper sealing head 2130 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces. The inner surface of the upper sealing head 2130 preferably includes one or more annular sealing members  
20 2210 for sealing the interface between the upper sealing head 2130 and the inner sealing mandrel 2120. The sealing members 2210 may comprise any number of conventional commercially available annular sealing members such as, for example, o-rings, polypak seals, or metal spring energized seals. In a preferred embodiment, the sealing members 2210 comprise polypak seals available from  
25 Parker Seals in order to optimally provide sealing for a long axial stroke.

In a preferred embodiment, the upper sealing head 2130 includes a shoulder 2215 for supporting the upper sealing head 2130 on the lower sealing head 2135.

The upper sealing head 2130 may be coupled to the outer sealing mandrel  
30 2140 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding or a standard threaded

WO 01/04535

PCT/US00/18635

connection. In a preferred embodiment, the upper sealing head 2130 is removably coupled to the outer sealing mandrel 2140 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the upper sealing head 2130 and the outer sealing mandrel 2140 includes one or more sealing members  
5 2220 for fluidically sealing the interface between the upper sealing head 2130 and the outer sealing mandrel 2140. The sealing members 2220 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals, or metal spring energized seals. In a preferred embodiment, the sealing members 2220 comprise polypak seals available from  
10 Parker Seals in order to optimally provide sealing for a long axial stroke.

The lower sealing head 2135 is coupled to the inner sealing mandrel 2120 and the load mandrel 2145. The lower sealing head 2135 is also movably coupled to the inner surface of the outer sealing mandrel 2140. In this manner, the upper sealing head 2130, outer sealing mandrel 2140, and expansion cone 2150  
15 reciprocate in the axial direction. The radial clearance between the outer surface of the lower sealing head 2135 and the inner surface of the outer sealing mandrel 2140 may range, for example, from about 0.0025 to 0.05 inches. In a preferred embodiment, the radial clearance between the outer surface of the lower sealing head 2135 and the inner surface of the outer sealing mandrel 2140 ranges from  
20 about 0.0025 to 0.05 inches in order to optimally provide minimal radial clearance.

The lower sealing head 2135 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The lower sealing head 2135 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel,  
25 carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the lower sealing head 2135 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces. The outer surface of the lower sealing head 2135 preferably includes one or more annular sealing members 2225 for sealing the interface between the lower sealing  
30 head 2135 and the outer sealing mandrel 2140. The sealing members 2225 may comprise any number of conventional commercially available annular sealing members such as, for example, o-rings, polypak seals or metal spring energized

seals. In a preferred embodiment, the sealing members 2225 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

The lower sealing head 2135 may be coupled to the inner sealing mandrel  
5 2120 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the lower sealing head 2135 is removably coupled to the inner sealing mandrel 2120 by a standard threaded  
10 connection. In a preferred embodiment, the mechanical coupling between the lower sealing head 2135 and the inner sealing mandrel 2120 includes one or more sealing members 2230 for fluidicly sealing the interface between the lower sealing head 2135 and the inner sealing mandrel 2120. The sealing members 2230 may  
comprise any number of conventional commercially available sealing members  
15 such as, for example, o-rings, polypak seals, or metal spring energized seals. In a preferred embodiment, the sealing members 2230 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

The lower sealing head 2135 may be coupled to the load mandrel 2145 using any number of conventional commercially available mechanical couplings such as,  
20 for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the lower sealing head 2135 is removably coupled to the load mandrel 2145 by a standard threaded connection. In a preferred  
embodiment, the mechanical coupling between the lower sealing head 2135 and  
25 the load mandrel 2145 includes one or more sealing members 2235 for fluidicly sealing the interface between the lower sealing head 1930 and the load mandrel 2145. The sealing members 2235 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals, or metal spring energized seals. In a preferred embodiment, the sealing  
30 members 2235 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

WO 01/04535

PCT/US00/18635

In a preferred embodiment, the lower sealing head 2135 includes a throat passage 2240 fluidically coupled between the fluid passages 2175 and 2180. The throat passage 2240 is preferably of reduced size and is adapted to receive and engage with a plug 2245, or other similar device. In this manner, the fluid passage 5 2175 is fluidically isolated from the fluid passage 2180. In this manner, the pressure chamber 2250 is pressurized.

The outer sealing mandrel 2140 is coupled to the upper sealing head 2130 and the expansion cone 2150. The outer sealing mandrel 2140 is also movably coupled to the inner surface of the casing 2155 and the outer surface of the lower 10 sealing head 2135. In this manner, the upper sealing head 2130, outer sealing mandrel 2140, and the expansion cone 2150 reciprocate in the axial direction. The radial clearance between the outer surface of the outer sealing mandrel 2140 and the inner surface of the casing 2155 may range, for example, from about 0.025 to 0.375 inches. In a preferred embodiment, the radial clearance between the outer 15 surface of the outer sealing mandrel 2140 and the inner surface of the casing 2155 ranges from about 0.025 to 0.125 inches in order to optimally provide stabilization for the expansion cone 2130 during the expansion process. The radial clearance between the inner surface of the outer sealing mandrel 2140 and the outer surface of the lower sealing head 2135 may range, for example, from about 0.005 to 0.125 20 inches. In a preferred embodiment, the radial clearance between the inner surface of the outer sealing mandrel 2140 and the outer surface of the lower sealing head 2135 ranges from about 0.005 to 0.010 inches in order to optimally provide minimal radial clearance.

The outer sealing mandrel 2140 preferably comprises an annular member 25 having substantially cylindrical inner and outer surfaces. The outer sealing mandrel 2140 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel, or other similar high strength materials. In a preferred embodiment, the outer sealing mandrel 2140 is fabricated from stainless 30 steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.



The outer sealing mandrel 2140 may be coupled to the upper sealing head 2130 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding or a standard threaded connection. In a preferred embodiment, the outer sealing mandrel 2140 is removably coupled to the upper sealing head 2130 by a standard threaded connection. The outer sealing mandrel 2140 may be coupled to the expansion cone 2150 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the outer sealing mandrel 2140 is removably coupled to the expansion cone 2150 by a standard threaded connection.

The upper sealing head 2130, the lower sealing head 2135, inner sealing mandrel 2120, and the outer sealing mandrel 2140 together define a pressure chamber 2250. The pressure chamber 2250 is fluidically coupled to the passage 2175 via one or more passages 2255. During operation of the apparatus 2100, the plug 2245 engages with the throat passage 2240 to fluidically isolate the fluid passage 2175 from the fluid passage 2180. The pressure chamber 2250 is then pressurized which in turn causes the upper sealing head 2130, outer sealing mandrel 2140, and expansion cone 2150 to reciprocate in the axial direction. The axial motion of the expansion cone 2150 in turn expands the casing 2155 in the radial direction.

The load mandrel 2145 is coupled to the lower sealing head 2135. The load mandrel 2145 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The load mandrel 2145 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the load mandrel 2145 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction bearing surfaces.

The load mandrel 2145 may be coupled to the lower sealing head 2135 using any number of conventional commercially available mechanical couplings such as,

for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding or a standard threaded connection. In a preferred embodiment, the load mandrel 2145 is removably coupled to the lower sealing head 2135 by a standard threaded connection in order to optimally provide  
5 high strength and permit easy replacement of the load mandrel 2145.

The load mandrel 2145 preferably includes a fluid passage 2180 that is adapted to convey fluidic materials from the fluid passage 2180 to the region outside of the apparatus 2100. In a preferred embodiment, the fluid passage 2180 is adapted to convey fluidic materials such as, for example, cement, epoxy, water,  
10 drilling mud, or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The expansion cone 2150 is coupled to the outer sealing mandrel 2140. The expansion cone 2150 is also movably coupled to the inner surface of the casing 2155. In this manner, the upper sealing head 2130, outer sealing mandrel 2140,  
15 and the expansion cone 2150 reciprocate in the axial direction. The reciprocation of the expansion cone 2150 causes the casing 2155 to expand in the radial direction.

The expansion cone 2150 preferably comprises an annular member having substantially cylindrical inner and conical outer surfaces. The outside radius of  
20 the outside conical surface may range, for example, from about 2 to 34 inches. In a preferred embodiment, the outside radius of the outside conical surface ranges from about 3 to 28 inches in order to optimally provide cone dimensions that are optimal for typical casings. The axial length of the expansion cone 2150 may range, for example, from about 2 to 6 times the largest outside diameter of the  
25 expansion cone 2150. In a preferred embodiment, the axial length of the expansion cone 2150 ranges from about 3 to 5 times the largest outside diameter of the expansion cone 2150 in order to optimally provide stability and centralization of the expansion cone 2150 during the expansion process. In a particularly preferred embodiment, the maximum outside diameter of the expansion cone 2150 is  
30 between about 90 to 100 % of the inside diameter of the existing wellbore that the casing 2155 will be joined with. In a preferred embodiment, the angle of attack of the expansion cone 2150 ranges from about 5 to 30 degrees in order to optimally

WO 01/04535

PCT/US00/18635

balance friction forces and radial expansion forces. The optimal expansion cone 2150 angle of attack will vary as a function of the particular operating conditions of the expansion operation.

The expansion cone 2150 may be fabricated from any number of  
5 conventional commercially available materials such as, for example, machine tool steel, nitride steel, titanium, tungsten carbide, ceramics, or other similar high strength materials. In a preferred embodiment, the expansion cone 2150 is fabricated from D2 machine tool steel in order to optimally provide high strength and resistance to wear and galling. In a particularly preferred embodiment, the  
10 outside surface of the expansion cone 2150 has a surface hardness ranging from about 58 to 62 Rockwell C in order to optimally provide resistance to wear.

The expansion cone 2150 may be coupled to the outside sealing mandrel  
2140 using any number of conventional commercially available mechanical  
couplings such as, for example, drillpipe connection, oilfield country tubular goods  
15 specialty type threaded connection, welding, amorphous bonding or a standard threaded connection. In a preferred embodiment, the expansion cone 2150 is coupled to the outside sealing mandrel 2140 using a standard threaded connection in order to optimally provide high strength and permit the expansion cone 2150 to be easily replaced.

20 The casing 2155 is removably coupled to the slips 2125 and expansion cone 2150. The casing 2155 preferably comprises a tubular member. The casing 2155 may be fabricated from any number of conventional commercially available materials such as, for example, slotted tubulars, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength material. In  
25 a preferred embodiment, the casing 2155 is fabricated from oilfield country tubular goods available from various foreign and domestic steel mills in order to optimally provide high strength.

In a preferred embodiment, the upper end 2260 of the casing 2155 includes a thin wall section 2265 and an outer annular sealing member 2270. In a preferred  
30 embodiment, the wall thickness of the thin wall section 2265 is about 50 to 100 % of the regular wall thickness of the casing 2155. In this manner, the upper end 2260 of the casing 2155 may be easily expanded and deformed into intimate

WO 01/04535

PCT/US00/18635

contact with the lower end of an existing section of wellbore casing. In a preferred embodiment, the lower end of the existing section of casing also includes a thin wall section. In this manner, the radial expansion of the thin walled section 2265 of casing 2155 into the thin walled section of the existing wellbore casing results  
5 in a wellbore casing having a substantially constant inside diameter.

The annular sealing member 2270 may be fabricated from any number of conventional commercially available sealing materials such as, for example, epoxy, rubber, metal or plastic. In a preferred embodiment, the annular sealing member 2270 is fabricated from StrataLock epoxy in order to optimally provide  
10 compressibility and resistance to wear. The outside diameter of the annular sealing member 2270 preferably ranges from about 70 to 95 % of the inside diameter of the lower section of the wellbore casing that the casing 2155 is joined to. In this manner, after expansion, the annular sealing member 2270 preferably provides a fluidic seal and also preferably provides sufficient frictional force with  
15 the inside surface of the existing section of wellbore casing during the radial expansion of the casing 2155 to support the casing 2155.

In a preferred embodiment, the lower end 2275 of the casing 2155 includes a thin wall section 2280 and an outer annular sealing member 2285. In a preferred embodiment, the wall thickness of the thin wall section 2280 is about 50 to 100 %  
20 of the regular wall thickness of the casing 2155. In this manner, the lower end 2275 of the casing 2155 may be easily expanded and deformed. Furthermore, in this manner, an other section of casing may be easily joined with the lower end 2275 of the casing 2155 using a radial expansion process. In a preferred embodiment, the upper end of the other section of casing also includes a thin wall  
25 section. In this manner, the radial expansion of the thin walled section of the upper end of the other casing into the thin walled section 2280 of the lower end of the casing 2155 results in a wellbore casing having a substantially constant inside diameter.

The annular sealing member 2285 may be fabricated from any number of  
30 conventional commercially available sealing materials such as, for example, epoxy, rubber, metal or plastic. In a preferred embodiment, the annular sealing member 2285 is fabricated from StrataLock epoxy in order to optimally provide

WO 01/04535

PCT/US00/18635

compressibility and wear resistance. The outside diameter of the annular sealing member 2285 preferably ranges from about 70 to 95 % of the inside diameter of the lower section of the existing wellbore casing that the casing 2155 is joined to. In this manner, the annular sealing member 2285 preferably provides a fluidic seal  
5 and also preferably provides sufficient frictional force with the inside wall of the wellbore during the radial expansion of the casing 2155 to support the casing 2155.

During operation, the apparatus 2100 is preferably positioned in a wellbore with the upper end 2260 of the casing 2155 positioned in an overlapping relationship with the lower end of an existing wellbore casing. In a particularly  
10 preferred embodiment, the thin wall section 2265 of the casing 2155 is positioned in opposing overlapping relation with the thin wall section and outer annular sealing member of the lower end of the existing section of wellbore casing. In this manner, the radial expansion of the casing 2155 will compress the thin wall sections and annular compressible members of the upper end 2260 of the casing  
15 2155 and the lower end of the existing wellbore casing into intimate contact. During the positioning of the apparatus 2100 in the wellbore, the casing 2155 is supported by the expansion cone 2150.

After positioning of the apparatus 2100, a first fluidic material is then pumped into the fluid passage 2160. The first fluidic material may comprise any  
20 number of conventional commercially available materials such as, for example, drilling mud, water, epoxy, or cement. In a preferred embodiment, the first fluidic material comprises a hardenable fluidic sealing material such as, for example, cement or epoxy in order to provide a hardenable outer annular body around the expanded casing 2155.

25 The first fluidic material may be pumped into the fluid passage 2160 at operating pressures and flow rates ranging, for example, from about 0 to 4,500 psi and 0 to 3,000 gallons/minute. In a preferred embodiment, the first fluidic material is pumped into the fluid passage 2160 at operating pressures and flow rates ranging from about 0 to 3,500 psi and 0 to 1,200 gallons/minute in order to  
30 optimally provide operational efficiency.

The first fluidic material pumped into the fluid passage 2160 passes through the fluid passages 2165, 2170, 2175, 2180 and then outside of the apparatus 2100.

The first fluidic material then fills the annular region between the outside of the apparatus 2100 and the interior walls of the wellbore.

The plug 2245 is then introduced into the fluid passage 2160. The plug 2245 lodges in the throat passage 2240 and fluidically isolates and blocks off the fluid passage 2175. In a preferred embodiment, a couple of volumes of a non-hardenable fluidic material are then pumped into the fluid passage 2160 in order to remove any hardenable fluidic material contained within and to ensure that none of the fluid passages are blocked.

A second fluidic material is then pumped into the fluid passage 2160. The second fluidic material may comprise any number of conventional commercially available materials such as, for example, drilling mud, water, drilling gases, or lubricants. In a preferred embodiment, the second fluidic material comprises a non-hardenable fluidic material such as, for example, water, drilling mud or lubricant in order to optimally provide pressurization of the pressure chamber 2250 and minimize frictional forces.

The second fluidic material may be pumped into the fluid passage 2160 at operating pressures and flow rates ranging, for example, from about 0 to 4,500 psi and 0 to 4,500 gallons/minute. In a preferred embodiment, the second fluidic material is pumped into the fluid passage 2160 at operating pressures and flow rates ranging from about 0 to 3,500 psi and 0 to 1,200 gallons/minute in order to optimally provide operational efficiency.

The second fluidic material pumped into the fluid passage 2160 passes through the fluid passages 2165, 2170, and 2175 into the pressure chambers 2195 of the slips 2125, and into the pressure chamber 2250. Continued pumping of the second fluidic material pressurizes the pressure chambers 2195 and 2250.

The pressurization of the pressure chambers 2195 causes the slip members 2205 to expand in the radial direction and grip the interior surface of the casing 2155. The casing 2155 is then preferably maintained in a substantially stationary position.

The pressurization of the pressure chamber 2250 causes the upper sealing head 2130, outer sealing mandrel 2140 and expansion cone 2150 to move in an

axial direction relative to the casing 2155. In this manner, the expansion cone 2150 will cause the casing 2155 to expand in the radial direction.

During the radial expansion process, the casing 2155 is prevented from moving in an upward direction by the slips 2125. A length of the casing 2155 is then expanded in the radial direction through the pressurization of the pressure chamber 2250. The length of the casing 2155 that is expanded during the expansion process will be proportional to the stroke length of the upper sealing head 2130, outer sealing mandrel 2140, and expansion cone 2150.

Upon the completion of a stroke, the operating pressure of the second fluidic material is reduced and the upper sealing head 2130, outer sealing mandrel 2140, and expansion cone 2150 drop to their rest positions with the casing 2155 supported by the expansion cone 2150. The position of the drillpipe 2105 is preferably adjusted throughout the radial expansion process in order to maintain the overlapping relationship between the thin walled sections of the lower end of the existing wellbore casing and the upper end of the casing 2155. In a preferred embodiment, the stroking of the expansion cone 2150 is then repeated, as necessary, until the thin walled section 2265 of the upper end 2260 of the casing 2155 is expanded into the thin walled section of the lower end of the existing wellbore casing. In this manner, a wellbore casing is formed including two adjacent sections of casing having a substantially constant inside diameter. This process may then be repeated for the entirety of the wellbore to provide a wellbore casing thousands of feet in length having a substantially constant inside diameter.

In a preferred embodiment, during the final stroke of the expansion cone 2150, the slips 2125 are positioned as close as possible to the thin walled section 2265 of the upper end of the casing 2155 in order to minimize slippage between the casing 2155 and the existing wellbore casing at the end of the radial expansion process. Alternatively, or in addition, the outside diameter of the annular sealing member 2270 is selected to ensure sufficient interference fit with the inside diameter of the lower end of the existing casing to prevent axial displacement of the casing 2155 during the final stroke. Alternatively, or in addition, the outside diameter of the annular sealing member 2285 is selected to provide an interference

fit with the inside walls of the wellbore at an earlier point in the radial expansion process so as to prevent further axial displacement of the casing 2155. In this final alternative, the interference fit is preferably selected to permit expansion of the casing 2155 by pulling the expansion cone 2150 out of the wellbore, without  
5 having to pressurize the pressure chamber 2250.

During the radial expansion process, the pressurized areas of the apparatus 2100 are limited to the fluid passages 2160, 2165, 2170, and 2175, the pressure chambers 2195 within the slips 2125, and the pressure chamber 2250. No fluid pressure acts directly on the casing 2155. This permits the use of operating  
10 pressures higher than the casing 2155 could normally withstand.

Once the casing 2155 has been completely expanded off of the expansion cone 2150, remaining portions of the apparatus 2100 are removed from the wellbore. In a preferred embodiment, the contact pressure between the deformed thin wall sections and compressible annular members of the lower end of the  
15 existing casing and the upper end 2260 of the casing 2155 ranges from about 500 to 40,000 psi in order to optimally support the casing 2155 using the existing wellbore casing.

In this manner, the casing 2155 is radially expanded into contact with an existing section of casing by pressurizing the interior fluid passages 2160, 2165,  
20 2170, and 2175 and the pressure chamber 2250 of the apparatus 2100.

In a preferred embodiment, as required, the annular body of hardenable fluidic material is then allowed to cure to form a rigid outer annular body about the expanded casing 2155. In the case where the casing 2155 is slotted, the cured fluidic material preferably permeates and envelops the expanded casing 2155. The  
25 resulting new section of wellbore casing includes the expanded casing 2155 and the rigid outer annular body. The overlapping joint between the pre-existing wellbore casing and the expanded casing 2155 includes the deformed thin wall sections and the compressible outer annular bodies. The inner diameter of the resulting combined wellbore casings is substantially constant. In this manner, a mono-  
30 diameter wellbore casing is formed. This process of expanding overlapping tubular members having thin wall end portions with compressible annular bodies into contact can be repeated for the entire length of a wellbore. In this manner, a



WO 01/04535

PCT/US00/18635

mono-diameter wellbore casing can be provided for thousands of feet in a subterranean formation.

In a preferred embodiment, as the expansion cone 2150 nears the upper end of the casing 2155, the operating flow rate of the second fluidic material is reduced in order to minimize shock to the apparatus 2100. In an alternative embodiment, the apparatus 2100 includes a shock absorber for absorbing the shock created by the completion of the radial expansion of the casing 2155.

In a preferred embodiment, the reduced operating pressure of the second fluidic material ranges from about 100 to 1,000 psi as the expansion cone 2130 nears the end of the casing 2155 in order to optimally provide reduced axial movement and velocity of the expansion cone 2130. In a preferred embodiment, the operating pressure of the second fluidic material is reduced during the return stroke of the apparatus 2100 to the range of about 0 to 500 psi in order minimize the resistance to the movement of the expansion cone 2130 during the return stroke. In a preferred embodiment, the stroke length of the apparatus 2100 ranges from about 10 to 45 feet in order to optimally provide equipment lengths that can be handled by conventional oil well rigging equipment while also minimizing the frequency at which the expansion cone 2130 must be stopped so that the apparatus 2100 can be re-stroked.

In an alternative embodiment, at least a portion of the upper sealing head 2130 includes an expansion cone for radially expanding the casing 2155 during operation of the apparatus 2100 in order to increase the surface area of the casing 2155 acted upon during the radial expansion process. In this manner, the operating pressures can be reduced.

Alternatively, the apparatus 2100 may be used to join a first section of pipeline to an existing section of pipeline. Alternatively, the apparatus 2100 may be used to directly line the interior of a wellbore with a casing, without the use of an outer annular layer of a hardenable material. Alternatively, the apparatus 2100 may be used to expand a tubular support member in a hole.

Referring now to Figures 17, 17a and 17b, another embodiment of an apparatus 2300 for expanding a tubular member will be described. The apparatus 2300 preferably includes a drillpipe 2305, an innerstring adapter 2310, a sealing

WO 01/04535

PCT/US00/18635

sleeve 2315, a hydraulic slip body 2320, hydraulic slips 2325, an inner sealing mandrel 2330, an upper sealing head 2335, a lower sealing head 2340, a load mandrel 2345, an outer sealing mandrel 2350, an expansion cone 2355, a mechanical slip body 2360, mechanical slips 2365, drag blocks 2370, casing 2375, fluid passages 2380, 2385, 2390, 2395, 2400, 2405, 2410, 2415, and 2485, and mandrel launcher 2480.

The drillpipe 2305 is coupled to the innerstring adapter 2310. During operation of the apparatus 2300, the drillpipe 2305 supports the apparatus 2300. The drillpipe 2305 preferably comprises a substantially hollow tubular member or members. The drillpipe 2305 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the drillpipe 2305 is fabricated from coiled tubing in order to facilitate the placement of the apparatus 2300 in non-vertical wellbores. The drillpipe 2305 may be coupled to the innerstring adapter 2310 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, or a standard threaded connection. In a preferred embodiment, the drillpipe 2305 is removably coupled to the innerstring adapter 2310 by a drillpipe connection.

The drillpipe 2305 preferably includes a fluid passage 2380 that is adapted to convey fluidic materials from a surface location into the fluid passage 2385. In a preferred embodiment, the fluid passage 2380 is adapted to convey fluidic materials such as, for example, cement, water, epoxy, drilling muds, or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 5,000 gallons/minute in order to optimally provide operational efficiency.

The innerstring adapter 2310 is coupled to the drill string 2305 and the sealing sleeve 2315. The innerstring adapter 2310 preferably comprises a substantially hollow tubular member or members. The innerstring adapter 2310 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred

WO 01/04535

PCT/US00/18635

embodiment, the innerstring adapter 2310 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

5 The innerstring adapter 2310 may be coupled to the drill string 2305 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, or a standard threaded connection. In a preferred embodiment, the innerstring adapter 2310 is removably coupled to the drill pipe 2305 by a drillpipe connection. The innerstring adapter 2310 may be coupled to the sealing sleeve  
10 2315 using any number of conventional commercially available mechanical couplings such as, for example, a drillpipe connection, oilfield country tubular goods specialty threaded connection, or a standard threaded connection. In a preferred embodiment, the innerstring adapter 2310 is removably-coupled to the sealing sleeve 2315 by a standard threaded connection.

15 The innerstring adapter 2310 preferably includes a fluid passage 2385 that is adapted to convey fluidic materials from the fluid passage 2380 into the fluid passage 2390. In a preferred embodiment, the fluid passage 2385 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud, drilling gases or lubricants at operating pressures and flow rates ranging from  
20 about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The sealing sleeve 2315 is coupled to the innerstring adapter 2310 and the hydraulic slip body 2320. The sealing sleeve 2315 preferably comprises a substantially hollow tubular member or members. The sealing sleeve 2315 may be fabricated from any number of conventional commercially available materials  
25 such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the sealing sleeve 2315 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low-friction surfaces.

The sealing sleeve 2315 may be coupled to the innerstring adapter 2310  
30 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connections, oilfield country tubular goods specialty threaded connections, or a standard threaded connection. In a preferred

embodiment, the sealing sleeve 2315 is removably coupled to the innerstring adapter 2310 by a standard threaded connection. The sealing sleeve 2315 may be coupled to the hydraulic slip body 2320 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe  
5 connection, oilfield country tubular goods specialty threaded connection, or a standard threaded connection. In a preferred embodiment, the sealing sleeve 2315 is removably coupled to the hydraulic slip body 2320 by a standard threaded connection.

The sealing sleeve 2315 preferably includes a fluid passage 2390 that is  
10 adapted to convey fluidic materials from the fluid passage 2385 into the fluid passage 2395. In a preferred embodiment, the fluid passage 2315 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud or lubricants at operating pressures and flow-rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The hydraulic slip body 2320 is coupled to the sealing sleeve 2315, the  
15 hydraulic slips 2325, and the inner sealing mandrel 2330. The hydraulic slip body 2320 preferably comprises a substantially hollow tubular member or members. The hydraulic slip body 2320 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular  
20 goods, low alloy steel, carbon steel, stainless steel or other high strength material. In a preferred embodiment, the hydraulic slip body 2320 is fabricated from carbon steel in order to optimally provide high strength at low cost.

The hydraulic slip body 2320 may be coupled to the sealing sleeve 2315 using any number of conventional commercially available mechanical couplings  
25 such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, or a standard threaded connection. In a preferred embodiment, the hydraulic slip body 2320 is removably coupled to the sealing sleeve 2315 by a standard threaded connection. The hydraulic slip body 2320 may be coupled to the slips 2325 using any number of conventional commercially  
30 available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding or a standard threaded connection. In a preferred embodiment, the hydraulic slip

body 2320 is removably coupled to the slips 2325 by a standard threaded connection. The hydraulic slip body 2320 may be coupled to the inner sealing mandrel 2330 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country  
5 tubular goods specialty threaded connection, welding, amorphous bonding or a standard threaded connection. In a preferred embodiment, the hydraulic slip body 2320 is removably coupled to the inner sealing mandrel 2330 by a standard threaded connection.

The hydraulic slips body 2320 preferably includes a fluid passage 2395 that  
10 is adapted to convey fluidic materials from the fluid passage 2390 into the fluid passage 2405. In a preferred embodiment, the fluid passage 2395 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000  
psi and 0 to 3,000 gallons/minute.

15 The hydraulic slips body 2320 preferably includes fluid passage 2400 that are adapted to convey fluidic materials from the fluid passage 2395 into the pressure chambers 2420 of the hydraulic slips 2325. In this manner, the slips 2325 are activated upon the pressurization of the fluid passage 2395 into contact with the inside surface of the casing 2375. In a preferred embodiment, the fluid  
20 passages 2400 are adapted to convey fluidic materials such as, for example, water, drilling mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The slips 2325 are coupled to the outside surface of the hydraulic slip body 2320. During operation of the apparatus 2300, the slips 2325 are activated upon  
25 the pressurization of the fluid passage 2395 into contact with the inside surface of the casing 2375. In this manner, the slips 2325 maintain the casing 2375 in a substantially stationary position.

The slips 2325 preferably include the fluid passages 2400, the pressure chambers 2420, spring bias 2425, and slip members 2430. The slips 2325 may  
30 comprise any number of conventional commercially available hydraulic slips such as, for example, RTTS packer tungsten carbide hydraulic slips or Model 3L retrievable bridge plug with hydraulic slips. In a preferred embodiment, the slips

2325 comprise RTTS packer tungsten carbide hydraulic slips available from Halliburton Energy Services in order to optimally provide resistance to axial movement of the casing 2375 during the radial expansion process.

The inner sealing mandrel 2330 is coupled to the hydraulic slip body 2320  
5 and the lower sealing head 2340. The inner sealing mandrel 2330 preferably comprises a substantially hollow tubular member or members. The inner sealing mandrel 2330 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a  
10 preferred embodiment, the inner sealing mandrel 2330 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

The inner sealing mandrel 2330 may be coupled to the hydraulic slip body 2320 using any number of conventional commercially available mechanical  
15 couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the inner sealing mandrel 2330 is removably coupled to the hydraulic slip body 2320 by a standard threaded connection. The inner sealing mandrel 2330 may be coupled to the lower sealing  
20 head 2340 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the inner sealing mandrel 2330 is removably coupled to the lower sealing head 2340 by a standard threaded  
25 connection.

The inner sealing mandrel 2330 preferably includes a fluid passage 2405 that is adapted to convey fluidic materials from the fluid passage 2395 into the fluid passage 2415. In a preferred embodiment, the fluid passage 2405 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling  
30 mud, or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

WO 01/04535

PCT/US00/18635

The upper sealing head 2335 is coupled to the outer sealing mandrel 2345 and expansion cone 2355. The upper sealing head 2335 is also movably coupled to the outer surface of the inner sealing mandrel 2330 and the inner surface of the casing 2375. In this manner, the upper sealing head 2335 reciprocates in the axial direction. The radial clearance between the inner cylindrical surface of the upper sealing head 2335 and the outer surface of the inner sealing mandrel 2330 may range, for example, from about 0.0025 to 0.05 inches. In a preferred embodiment, the radial clearance between the inner cylindrical surface of the upper sealing head 2335 and the outer surface of the inner sealing mandrel 2330 ranges from about 0.005 to 0.01 inches in order to optimally provide minimal clearance. The radial clearance between the outer cylindrical surface of the upper sealing head 2335 and the inner surface of the casing 2375 may range, for example, from about 0.025 to 0.375 inches. In a preferred embodiment, the radial clearance between the outer cylindrical surface of the upper sealing head 2335 and the inner surface of the casing 2375 ranges from about 0.025 to 0.125 inches in order to optimally provide stabilization for the expansion cone 2355 during the expansion process.

The upper sealing head 2335 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The upper sealing head 2335 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the upper sealing head 2335 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces. The inner surface of the upper sealing head 2335 preferably includes one or more annular sealing members 2435 for sealing the interface between the upper sealing head 2335 and the inner sealing mandrel 2330. The sealing members 2435 may comprise any number of conventional commercially available annular sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2435 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

WO 01/04535

PCT/US00/18635

In a preferred embodiment, the upper sealing head 2335 includes a shoulder 2440 for supporting the upper sealing head on the lower sealing head 1930.

The upper sealing head 2335 may be coupled to the outer sealing mandrel 2350 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the upper sealing head 2335 is removably coupled to the outer sealing mandrel 2350 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the upper sealing head 2335 and the outer sealing mandrel 2350 includes one or more sealing members 2445 for fluidically sealing the interface between the upper sealing head 2335 and the outer sealing mandrel 2350. The sealing members 2445 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2445 comprise polypak seals available from Parker Seals in order to optimally provide sealing for long axial strokes.

The lower sealing head 2340 is coupled to the inner sealing mandrel 2330 and the load mandrel 2345. The lower sealing head 2340 is also movably coupled to the inner surface of the outer sealing mandrel 2350. In this manner, the upper sealing head 2335 and outer sealing mandrel 2350 reciprocate in the axial direction. The radial clearance between the outer surface of the lower sealing head 2340 and the inner surface of the outer sealing mandrel 2350 may range, for example, from about 0.0025 to 0.05 inches. In a preferred embodiment, the radial clearance between the outer surface of the lower sealing head 2340 and the inner surface of the outer sealing mandrel 2350 ranges from about 0.005 to 0.010 inches in order to optimally provide minimal radial clearance.

The lower sealing head 2340 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The lower sealing head 2340 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield tubular members, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the lower sealing head 2340 is fabricated from stainless steel in order



WO 01/04535

PCT/US00/18635

to optimally provide high strength, corrosion resistance, and low friction surfaces. The outer surface of the lower sealing head 2340 preferably includes one or more annular sealing members 2450 for sealing the interface between the lower sealing head 2340 and the outer sealing mandrel 2350. The sealing members 2450 may  
5 comprise any number of conventional commercially available annular sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2450 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

10 The lower sealing head 2340 may be coupled to the inner sealing mandrel 2330 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular specialty threaded connection, welding, amorphous bonding, or standard threaded  
15 coupled to the inner sealing mandrel 2330 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the lower sealing head 2340 and the inner sealing mandrel 2330 includes one or more sealing members 2455 for fluidically sealing the interface between the lower sealing head 2340 and the inner sealing mandrel 2330. The sealing members 2455 may comprise any  
20 number of conventional commercially available sealing members such as, for example, o-rings, polypak or metal spring energized seals. In a preferred embodiment, the sealing members 2455 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke length.

The lower sealing head 2340 may be coupled to the load mandrel 2345 using  
25 any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding or a standard threaded connection. In a preferred embodiment, the lower sealing head 2340 is removably coupled to the load mandrel 2345 by a standard threaded connection. In a preferred  
30 embodiment, the mechanical coupling between the lower sealing head 2340 and the load mandrel 2345 includes one or more sealing members 2460 for fluidically sealing the interface between the lower sealing head 2340 and the load mandrel

2345. The sealing members 2460 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2460 comprise polypak seals available from Parker Seals in order to  
5 optimally provide sealing for a long axial stroke length.

In a preferred embodiment, the lower sealing head 2340 includes a throat passage 2465 fluidicly coupled between the fluid passages 2405 and 2415. The throat passage 2465 is preferably of reduced size and is adapted to receive and engage with a plug 2470, or other similar device. In this manner, the fluid passage  
10 2405 is fluidicly isolated from the fluid passage 2415. In this manner, the pressure chamber 2475 is pressurized.

The outer sealing mandrel 2350 is coupled to the upper sealing head 2335 and the expansion cone 2355. The outer sealing mandrel 2350 is also movably coupled to the inner surface of the casing 2375 and the outer surface of the lower  
15 sealing head 2340. In this manner, the upper sealing head 2335, outer sealing mandrel 2350, and the expansion cone 2355 reciprocate in the axial direction. The radial clearance between the outer surface of the outer sealing mandrel 2350 and the inner surface of the casing 2375 may range, for example, from about 0.025 to 0.375 inches. In a preferred embodiment, the radial clearance between the outer  
20 surface of the outer sealing mandrel 2350 and the inner surface of the casing 2375 ranges from about 0.025 to 0.125 inches in order to optimally provide stabilization for the expansion cone 2355 during the expansion process. The radial clearance between the inner surface of the outer sealing mandrel 2350 and the outer surface of the lower sealing head 2340 may range, for example, from about 0.0025 to 0.375  
25 inches. In a preferred embodiment, the radial clearance between the inner surface of the outer sealing mandrel 2350 and the outer surface of the lower sealing head 2340 ranges from about 0.005 to 0.010 inches in order to optimally provide minimal clearance.

The outer sealing mandrel 2350 preferably comprises an annular member  
30 having substantially cylindrical inner and outer surfaces. The outer sealing mandrel 2350 may be fabricated from any number of conventional commercially available materials such as, for example, low alloy steel, carbon steel, stainless steel

WO 01/04535

PCT/US00/18635

or other similar high strength materials. In a preferred embodiment, the outer sealing mandrel 2350 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

The outer sealing mandrel 2350 may be coupled to the upper sealing head 2335 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connections, oilfield country tubular goods specialty threaded connections, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the outer sealing mandrel 2350 is removably coupled to the upper sealing head 2335 by a standard threaded connection. The outer sealing mandrel 2350 may be coupled to the expansion cone 2355 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection; welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the outer sealing mandrel 2350 is removably coupled to the expansion cone 2355 by a standard threaded connection.

The upper sealing head 2335, the lower sealing head 2340, the inner sealing mandrel 2330, and the outer sealing mandrel 2350 together define a pressure chamber 2475. The pressure chamber 2475 is fluidically coupled to the passage 2405 via one or more passages 2410. During operation of the apparatus 2300, the plug 2470 engages with the throat passage 2465 to fluidically isolate the fluid passage 2415 from the fluid passage 2405. The pressure chamber 2475 is then pressurized which in turn causes the upper sealing head 2335, outer sealing mandrel 2350, and expansion cone 2355 to reciprocate in the axial direction. The axial motion of the expansion cone 2355 in turn expands the casing 2375 in the radial direction.

The load mandrel 2345 is coupled to the lower sealing head 2340 and the mechanical slip body 2360. The load mandrel 2345 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The load mandrel 2345 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the load mandrel 2345 is fabricated from

stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

The load mandrel 2345 may be coupled to the lower sealing head 2340 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding or a standard threaded connection. In a preferred embodiment, the load mandrel 2345 is removably coupled to the lower sealing head 2340 by a standard threaded connection. The load mandrel 2345 may be coupled to the mechanical slip body 2360 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the load mandrel 2345 is removably coupled to the mechanical slip body 2360 by a standard threaded connection.

The load mandrel 2345 preferably includes a fluid passage 2415 that is adapted to convey fluidic materials from the fluid passage 2405 to the region outside of the apparatus 2300. In a preferred embodiment, the fluid passage 2415 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The expansion cone 2355 is coupled to the outer sealing mandrel 2350. The expansion cone 2355 is also movably coupled to the inner surface of the casing 2375. In this manner, the upper sealing head 2335, outer sealing mandrel 2350, and the expansion cone 2355 reciprocate in the axial direction. The reciprocation of the expansion cone 2355 causes the casing 2375 to expand in the radial direction.

The expansion cone 2355 preferably comprises an annular member having substantially cylindrical inner and conical outer surfaces. The outside radius of the outside conical surface may range, for example, from about 2 to 34 inches. In a preferred embodiment, the outside radius of the outside conical surface ranges from about 3 to 28 inches in order to optimally provide radial expansion of the typical casings. The axial length of the expansion cone 2355 may range, for

WO 01/04535

PCT/US00/18635

example, from about 2 to 8 times the largest outside diameter of the expansion cone 2355. In a preferred embodiment, the axial length of the expansion cone 2355 ranges from about 3 to 5 times the largest outside diameter of the expansion cone 2355 in order to optimally provide stability and centralization of the expansion  
5 cone 2355 during the expansion process. In a preferred embodiment, the angle of attack of the expansion cone 2355 ranges from about 5 to 30 degrees in order to optimally frictional forces with radial expansion forces. The optimum angle of attack of the expansion cone 2355 will vary as a function of the operating parameters of the particular expansion operation.

10 The expansion cone 2355 may be fabricated from any number of conventional commercially available materials such as, for example, machine tool steel, nitride steel, titanium, tungsten carbide, ceramics or other similar high strength materials. In a preferred embodiment, the expansion cone 2355 is  
fabricated from D2 machine tool steel in order to optimally provide high strength,  
15 abrasion resistance, and galling resistance. In a particularly preferred embodiment, the outside surface of the expansion cone 2355 has a surface hardness ranging from about 58 to 62 Rockwell C in order to optimally provide high strength, abrasion resistance, resistance to galling.

The expansion cone 2355 may be coupled to the outside sealing mandrel  
20 2350 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the expansion cone 2355 is coupled to the outside sealing mandrel 2350 using a standard threaded connection  
25 in order to optimally provide high strength and permit the expansion cone 2355 to be easily replaced.

The mandrel launcher 2480 is coupled to the casing 2375. The mandrel launcher 2480 comprises a tubular section of casing having a reduced wall thickness compared to the casing 2375. In a preferred embodiment, the wall  
30 thickness of the mandrel launcher 2480 is about 50 to 100 % of the wall thickness of the casing 2375. In this manner, the initiation of the radial expansion of the

WO 01/04535

PCT/US00/18635

casing 2375 is facilitated, and the placement of the apparatus 2300 into a wellbore casing and wellbore is facilitated.

The mandrel launcher 2480 may be coupled to the casing 2375 using any number of conventional mechanical couplings. The mandrel launcher 2480 may  
5 have a wall thickness ranging, for example, from about 0.15 to 1.5 inches. In a preferred embodiment, the wall thickness of the mandrel launcher 2480 ranges from about 0.25 to 0.75 inches in order to optimally provide high strength in a minimal profile. The mandrel launcher 2480 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield  
10 tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the mandrel launcher 2480 is fabricated from oilfield tubular goods having a higher strength than that of the casing 2375 but with a smaller wall thickness than the casing 2375 in order to optimally provide a thin walled container having approximately the same burst  
15 strength as that of the casing 2375.

The mechanical slip body 2460 is coupled to the load mandrel 2345, the mechanical slips 2365, and the drag blocks 2370. The mechanical slip body 2460 preferably comprises a tubular member having an inner passage 2485 fluidically coupled to the passage 2415. In this manner, fluidic materials may be conveyed  
20 from the passage 2484 to a region outside of the apparatus 2300.

The mechanical slip body 2360 may be coupled to the load mandrel 2345 using any number of conventional mechanical couplings. In a preferred embodiment, the mechanical slip body 2360 is removably coupled to the load mandrel 2345 using threads and sliding steel retaining rings in order to optimally  
25 provide a high strength attachment. The mechanical slip body 2360 may be coupled to the mechanical slips 2365 using any number of conventional mechanical couplings. In a preferred embodiment, the mechanical slip body 2360 is removably coupled to the mechanical slips 2365 using threads and sliding steel retaining rings in order to optimally provide a high strength attachment. The mechanical slip  
30 body 2360 may be coupled to the drag blocks 2370 using any number of conventional mechanical couplings. In a preferred embodiment, the mechanical slip body 2360 is removably coupled to the drag blocks 2365 using threads and

WO 01/04535

PCT/US00/18635

sliding steel retaining rings in order to optimally provide a high strength attachment.

The mechanical slips 2365 are coupled to the outside surface of the mechanical slip body 2360. During operation of the apparatus 2300, the  
5 mechanical slips 2365 prevent upward movement of the casing 2375 and mandrel launcher 2480. In this manner, during the axial reciprocation of the expansion cone 2355, the casing 2375 and mandrel launcher 2480 are maintained in a substantially stationary position. In this manner, the mandrel launcher 2480 and casing 2375 are expanded in the radial direction by the axial movement of the  
10 expansion cone 2355.

The mechanical slips 2365 may comprise any number of conventional commercially available mechanical slips such as, for example, RTTS packer tungsten carbide mechanical slips, RTTS packer wicker type mechanical slips or Model 3L retrievable bridge plug tungsten carbide upper mechanical slips. In a  
15 preferred embodiment, the mechanical slips 2365 comprise RTTS packer tungsten carbide mechanical slips available from Halliburton Energy Services in order to optimally provide resistance to axial movement of the casing 2375 during the expansion process.

The drag blocks 2370 are coupled to the outside surface of the mechanical  
20 slip body 2360. During operation of the apparatus 2300, the drag blocks 2370 prevent upward movement of the casing 2375 and mandrel launcher 2480. In this manner, during the axial reciprocation of the expansion cone 2355, the casing 2375 and mandrel launcher 2480 are maintained in a substantially stationary position. In this manner, the mandrel launcher 2480 and casing 2375 are expanded in the  
25 radial direction by the axial movement of the expansion cone 2355.

The drag blocks 2370 may comprise any number of conventional commercially available mechanical slips such as, for example, RTTS packer mechanical drag blocks or Model 3L retrievable bridge plug drag blocks. In a  
30 preferred embodiment, the drag blocks 2370 comprise RTTS packer mechanical drag blocks available from Halliburton Energy Services in order to optimally provide resistance to axial movement of the casing 2375 during the expansion process.

WO 01/04535

PCT/US00/18635

The casing 2375 is coupled to the mandrel launcher 2480. The casing 2375 is further removably coupled to the mechanical slips 2365 and drag blocks 2370. The casing 2375 preferably comprises a tubular member. The casing 2375 may be fabricated from any number of conventional commercially available materials such as, for example, slotted tubulars, oil country tubular goods, carbon steel, low alloy steel, stainless steel or other similar high strength materials. In a preferred embodiment, the casing 2375 is fabricated from oilfield country tubular goods available from various foreign and domestic steel mills in order to optimally provide high strength. In a preferred embodiment, the upper end of the casing 2375 includes one or more sealing members positioned about the exterior of the casing 2375.

During operation, the apparatus 2300 is positioned in a wellbore with the upper end of the casing 2375 positioned in an overlapping relationship within an existing wellbore casing. In order minimize surge pressures within the borehole during placement of the apparatus 2300, the fluid passage 2380 is preferably provided with one or more pressure relief passages. During the placement of the apparatus 2300 in the wellbore, the casing 2375 is supported by the expansion cone 2355.

After positioning of the apparatus 2300 within the bore hole in an overlapping relationship with an existing section of wellbore casing, a first fluidic material is pumped into the fluid passage 2380 from a surface location. The first fluidic material is conveyed from the fluid passage 2380 to the fluid passages 2385, 2390, 2395, 2405, 2415, and 2485. The first fluidic material will then exit the apparatus 2300 and fill the annular region between the outside of the apparatus 2300 and the interior walls of the bore hole.

The first fluidic material may comprise any number of conventional commercially available materials such as, for example, epoxy, drilling mud, slag mix, cement, or water. In a preferred embodiment, the first fluidic material comprises a hardenable fluidic sealing material such as, for example, slag mix, epoxy, or cement. In this manner, a wellbore casing having an outer annular layer of a hardenable material may be formed.



The first fluidic material may be pumped into the apparatus 2300 at operating pressures and flow rates ranging, for example, from about 0 to 4,500 psi, and 0 to 3,000 gallons/minute. In a preferred embodiment, the first fluidic material is pumped into the apparatus 2300 at operating pressures and flow rates  
5 ranging from about 0 to 3,500 psi and 0 to 1,200 gallons/minute in order to optimally provide operational efficiency.

At a predetermined point in the injection of the first fluidic material such as, for example, after the annular region outside of the apparatus 2300 has been filled to a predetermined level, a plug 2470, dart, or other similar device is  
10 introduced into the first fluidic material. The plug 2470 lodges in the throat passage 2465 thereby fluidically isolating the fluid passage 2405 from the fluid passage 2415.

After placement of the plug 2470 in the throat passage 2465, a second fluidic material is pumped into the fluid passage 2380 in order to pressurize the pressure  
15 chamber 2475. The second fluidic material may comprise any number of conventional commercially available materials such as, for example, water, drilling gases, drilling mud or lubricants. In a preferred embodiment, the second fluidic material comprises a non-hardenable fluidic material such as, for example, water, drilling mud or lubricant.

20 The second fluidic material may be pumped into the apparatus 2300 at operating pressures and flow rates ranging, for example, from about 0 to 4,500 psi and 0 to 4,500 gallons/minute. In a preferred embodiment, the second fluidic material is pumped into the apparatus 2300 at operating pressures and flow rates ranging from about 0 to 3,500 psi and 0 to 1,200 gallons/minute in order to  
25 optimally provide operational efficiency.

The pressurization of the pressure chamber 2475 causes the upper sealing head 2335, outer sealing mandrel 2350, and expansion cone 2355 to move in an axial direction. The pressurization of the pressure chamber 2475 also causes the hydraulic slips 2325 to expand in the radial direction and hold the casing 2375 in  
30 a substantially stationary position. Furthermore, as the expansion cone 2355 moves in the axial direction, the expansion cone 2355 pulls the mandrel launcher 2480 and drag blocks 2370 along, which sets the mechanical slips 2365 and stops

further axial movement of the mandrel launcher 2480 and casing 2375. In this manner, the axial movement of the expansion cone 2355 radially expands the mandrel launcher 2480 and casing 2375.

Once the upper sealing head 2335, outer sealing mandrel 2350, and expansion cone 2355 complete an axial stroke, the operating pressure of the second fluidic material is reduced. The reduction in the operating pressure of the second fluidic material releases the hydraulic slips 2325. The drill string 2305 is then raised. This causes the inner sealing mandrel 2330, lower sealing head 2340, load mandrel 2345, and mechanical slip body 2360 to move upward. This unsets the mechanical slips 2365 and permits the mechanical slips 2365 and drag blocks 2370 to be moved within the mandrel launcher 2480 and casing 2375. When the lower sealing head 2340 contacts the upper sealing head 2335, the second fluidic material is again pressurized and the radial expansion process continues. In this manner, the mandrel launcher 2480 and casing 2375 are radial expanded through repeated axial strokes of the upper sealing head 2335, outer sealing mandrel 2350 and expansion cone 2355. Throughout the radial expansion process, the upper end of the casing 2375 is preferably maintained in an overlapping relation with an existing section of wellbore casing.

At the end of the radial expansion process, the upper end of the casing 2375 is expanded into intimate contact with the inside surface of the lower end of the existing wellbore casing. In a preferred embodiment, the sealing members provided at the upper end of the casing 2375 provide a fluidic seal between the outside surface of the upper end of the casing 2375 and the inside surface of the lower end of the existing wellbore casing. In a preferred embodiment, the contact pressure between the casing 2375 and the existing section of wellbore casing ranges from about 400 to 10,000 psi in order to optimally provide contact pressure, activate the sealing members, and withstand typical tensile and compressive loading conditions.

In a preferred embodiment, as the expansion cone 2355 nears the upper end of the casing 2375, the operating pressure of the second fluidic material is reduced in order to minimize shock to the apparatus 2300. In an alternative embodiment,

WO 01/04535

PCT/US00/18635

the apparatus 2300 includes a shock absorber for absorbing the shock created by the completion of the radial expansion of the casing 2375.

In a preferred embodiment, the reduced operating pressure of the second fluidic material ranges from about 100 to 1,000 psi as the expansion cone 2355  
5       nears the end of the casing 2375 in order to optimally provide reduced axial movement and velocity of the expansion cone 2355. In a preferred embodiment, the operating pressure of the second fluidic material is reduced during the return stroke of the apparatus 2300 to the range of about 0 to 500 psi in order minimize the resistance to the movement of the expansion cone 2355 during the return  
10       stroke. In a preferred embodiment, the stroke length of the apparatus 2300 ranges from about 10 to 45 feet in order to optimally provide equipment that can be handled by typical oil well rigging equipment and minimize the frequency at which the expansion cone 2355 must be stopped to permit the apparatus 2300 to be re-stroked.

15       In an alternative embodiment, at least a portion of the upper sealing head 2335 includes an expansion cone for radially expanding the mandrel launcher 2480 and casing 2375 during operation of the apparatus 2300 in order to increase the surface area of the casing 2375 acted upon during the radial expansion process. In this manner, the operating pressures can be reduced.

20       In an alternative embodiment, mechanical slips 2365 are positioned in an axial location between the sealing sleeve 2315 and the inner sealing mandrel 2330 in order to optimally the construction and operation of the apparatus 2300.

Upon the complete radial expansion of the casing 2375, if applicable, the first fluidic material is permitted to cure within the annular region between the  
25       outside of the expanded casing 2375 and the interior walls of the wellbore. In the case where the casing 2375 is slotted, the cured fluidic material preferably permeates and envelops the expanded casing 2375. In this manner, a new section of wellbore casing is formed within a wellbore. Alternatively, the apparatus 2300 may be used to join a first section of pipeline to an existing section of pipeline.  
30       Alternatively, the apparatus 2300 may be used to directly line the interior of a wellbore with a casing, without the use of an outer annular layer of a hardenable

WO 01/04535

PCT/US00/18635

material. Alternatively, the apparatus 2300 may be used to expand a tubular support member in a hole.

During the radial expansion process, the pressurized areas of the apparatus 2300 are limited to the fluid passages 2380, 2385, 2390, 2395, 2400, 2405, and 2410, and the pressure chamber 2475. No fluid pressure acts directly on the mandrel launcher 2480 and casing 2375. This permits the use of operating pressures higher than the mandrel launcher 2480 and casing 2375 could normally withstand.

Referring now to Figure 18, a preferred embodiment of an apparatus 2500 for forming a mono-diameter wellbore casing will be described. The apparatus 2500 preferably includes a drillpipe 2505, an innerstring adapter 2510, a sealing sleeve 2515, a hydraulic slip body 2520, hydraulic slips 2525, an inner sealing mandrel 2530, upper sealing head 2535, lower sealing head 2540, outer sealing mandrel 2545, load mandrel 2550, expansion cone 2555, casing 2560, and fluid passages 2565, 2570, 2575, 2580, 2585, 2590, 2595, and 2600.

The drillpipe 2505 is coupled to the innerstring adapter 2510. During operation of the apparatus 2500, the drillpipe 2505 supports the apparatus 2500. The drillpipe 2505 preferably comprises a substantially hollow tubular member or members. The drillpipe 2505 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the drillpipe 2505 is fabricated from coiled tubing in order to facilitate the placement of the apparatus 2500 in non-vertical wellbores. The drillpipe 2505 may be coupled to the innerstring adapter 2510 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, or a standard threaded connection. In a preferred embodiment, the drillpipe 2505 is removably coupled to the innerstring adapter 2510 by a drillpipe connection. a drillpipe connection provides the advantages of high strength and easy disassembly.

The drillpipe 2505 preferably includes a fluid passage 2565 that is adapted to convey fluidic materials from a surface location into the fluid passage 2570. In

WO 01/04535

PCT/US00/18635

a preferred embodiment, the fluid passage 2565 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud, or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

5       The innerstring adapter 2510 is coupled to the drill string 2505 and the sealing sleeve 2515. The innerstring adapter 2510 preferably comprises a substantially hollow tubular member or members. The innerstring adapter 2510 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel,  
10 carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the innerstring adapter 2510 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

      The innerstring adapter 2510 may be coupled to the drill string 2505 using  
15 any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, or a standard threaded connection. In a preferred embodiment, the innerstring adapter 2510 is removably coupled to the drill pipe 2505 by a drillpipe connection. The innerstring adapter 2510 may be coupled to  
20 the sealing sleeve 2515 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection or a standard threaded connection. In a preferred embodiment, the innerstring adapter 2510 is removably coupled to the sealing sleeve 2515 by a  
25 standard threaded connection.

      The innerstring adapter 2510 preferably includes a fluid passage 2570 that is adapted to convey fluidic materials from the fluid passage 2565 into the fluid passage 2575. In a preferred embodiment, the fluid passage 2570 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud  
30 or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

WO 01/04535

PCT/US00/18635

The sealing sleeve 2515 is coupled to the innerstring adapter 2510 and the hydraulic slip body 2520. The sealing sleeve 2515 preferably comprises a substantially hollow tubular member or members. The sealing sleeve 2515 may be fabricated from any number of conventional commercially available materials  
5 such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the sealing sleeve 2515 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low-friction surfaces.

The sealing sleeve 2515 may be coupled to the innerstring adapter 2510  
10 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connections, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection, or a standard threaded connection. In a preferred embodiment, the sealing sleeve 2515 is removably coupled to the innerstring adapter 2510 by a standard threaded  
15 connection. The sealing sleeve 2515 may be coupled to the hydraulic slip body 2520 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection, or a standard threaded connection. In a preferred embodiment, the sealing sleeve 2515  
20 is removably coupled to the hydraulic slip body 2520 by a standard threaded connection.

The sealing sleeve 2515 preferably includes a fluid passage 2575 that is adapted to convey fluidic materials from the fluid passage 2570 into the fluid passage 2580. In a preferred embodiment, the fluid passage 2575 is adapted to  
25 convey fluidic materials such as, for example, cement, epoxy, water, drilling mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The hydraulic slip body 2520 is coupled to the sealing sleeve 2515, the hydraulic slips 2525, and the inner sealing mandrel 2530. The hydraulic slip body  
30 2520 preferably comprises a substantially hollow tubular member or members. The hydraulic slip body 2520 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular

WO 01/04535

PCT/US00/18635

goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the hydraulic slip body 2520 is fabricated from carbon steel in order to optimally provide high strength.

- The hydraulic slip body 2520 may be coupled to the sealing sleeve 2515
- 5 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection or a standard threaded connection. In a preferred embodiment, the hydraulic slip body 2520 is removably coupled to the sealing sleeve 2515 by a standard threaded connection.
- 10 The hydraulic slip body 2520 may be coupled to the slips 2525 using any number of conventional commercially available mechanical couplings such as, for example, threaded connection or welding. In a preferred embodiment, the hydraulic slip body 2520 is removably coupled to the slips 2525 by a threaded connection. The hydraulic slip body 2520 may be coupled to the inner sealing mandrel 2530 using
- 15 any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, welding, amorphous bonding or a standard threaded connection. In a preferred embodiment, the hydraulic slip body 2520 is removably coupled to the inner sealing mandrel 2530 by a standard threaded connection.
- 20 The hydraulic slips body 2520 preferably includes a fluid passage 2580 that is adapted to convey fluidic materials from the fluid passage 2575 into the fluid passage 2590. In a preferred embodiment, the fluid passage 2580 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000
- 25 psi and 0 to 3,000 gallons/minute.

- The hydraulic slips body 2520 preferably includes fluid passages 2585 that are adapted to convey fluidic materials from the fluid passage 2580 into the pressure chambers of the hydraulic slips 2525. In this manner, the slips 2525 are activated upon the pressurization of the fluid passage 2580 into contact with the
- 30 inside surface of the casing 2560. In a preferred embodiment, the fluid passages 2585 are adapted to convey fluidic materials such as, for example, water, drilling

mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The slips 2525 are coupled to the outside surface of the hydraulic slip body 2520. During operation of the apparatus 2500, the slips 2525 are activated upon the pressurization of the fluid passage 2580 into contact with the inside surface of the casing 2560. In this manner, the slips 2525 maintain the casing 2560 in a substantially stationary position.

The slips 2525 preferably include the fluid passages 2585, the pressure chambers 2605, spring bias 2610, and slip members 2615. The slips 2525 may comprise any number of conventional commercially available hydraulic slips such as, for example, RTTS packer tungsten carbide hydraulic slips or Model 3L retrievable bridge plug with hydraulic slips. In a preferred embodiment, the slips 2525 comprise RTTS packer tungsten carbide hydraulic slips available from Halliburton Energy Services in order to optimally provide resistance to axial movement of the casing 2560 during the expansion process.

The inner sealing mandrel 2530 is coupled to the hydraulic slip body 2520 and the lower sealing head 2540. The inner sealing mandrel 2530 preferably comprises a substantially hollow tubular member or members. The inner sealing mandrel 2530 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the inner sealing mandrel 2530 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

The inner sealing mandrel 2530 may be coupled to the hydraulic slip body 2520 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the inner sealing mandrel 2530 is removably coupled to the hydraulic slip body 2520 by a standard threaded connection. The inner sealing mandrel 2530 may be coupled to the lower sealing head 2540 using any number of conventional commercially available mechanical



WO 01/04535

PCT/US00/18635

couplings such as, for example, oilfield country tubular goods specialty type threaded connection, drillpipe connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the inner sealing mandrel 2530 is removably coupled to the lower sealing head 2540 by a standard  
5 threaded connection.

The inner sealing mandrel 2530 preferably includes a fluid passage 2590 that is adapted to convey fluidic materials from the fluid passage 2580 into the fluid passage 2600. In a preferred embodiment, the fluid passage 2590 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud  
10 or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The upper sealing head 2535 is coupled to the outer sealing mandrel 2545 and expansion cone 2555. The upper sealing head 2535 is also movably coupled to the outer surface of the inner sealing mandrel 2530 and the inner surface of the casing 2560. In this manner, the upper sealing head 2535 reciprocates in the axial  
15 direction. The radial clearance between the inner cylindrical surface of the upper sealing head 2535 and the outer surface of the inner sealing mandrel 2530 may range, for example, from about 0.0025 to 0.05 inches. In a preferred embodiment, the radial clearance between the inner cylindrical surface of the upper sealing head  
20 2535 and the outer surface of the inner sealing mandrel 2530 ranges from about 0.005 to 0.01 inches in order to optimally provide minimal radial clearance. The radial clearance between the outer cylindrical surface of the upper sealing head 2535 and the inner surface of the casing 2560 may range, for example, from about 0.025 to 0.375 inches. In a preferred embodiment, the radial clearance between  
25 the outer cylindrical surface of the upper sealing head 2535 and the inner surface of the casing 2560 ranges from about 0.025 to 0.125 inches in order to optimally provide stabilization for the expansion cone 2535 during the expansion process.

The upper sealing head 2535 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The upper sealing head  
30 2535 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel,

WO 01/04535

PCT/US00/18635

carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the upper sealing head 2535 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces. The inner surface of the upper sealing head 2535 preferably includes one or more  
5 annular sealing members 2620 for sealing the interface between the upper sealing head 2535 and the inner sealing mandrel 2530. The sealing members 2620 may comprise any number of conventional commercially available annular sealing members such as, for example, o-rings, polypak seals, or metal spring energized seals. In a preferred embodiment, the sealing members 2620 comprise polypak  
10 seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

In a preferred embodiment, the upper sealing head 2535 includes a shoulder 2625 for supporting the upper sealing head 2535, outer sealing mandrel 2545, and expansion cone 2555 on the lower sealing head 2540.

15 The upper sealing head 2535 may be coupled to the outer sealing mandrel 2545 using any number of conventional commercially available mechanical couplings such as, for example, oilfield country tubular goods specialty threaded connection, pipeline connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the upper sealing head 2535 is  
20 removably coupled to the outer sealing mandrel 2545 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the upper sealing head 2535 and the outer sealing mandrel 2545 includes one or more sealing members 2630 for fluidically sealing the interface between the upper sealing head 2535 and the outer sealing mandrel 2545. The sealing members 2630 may  
25 comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2630 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

The lower sealing head 2540 is coupled to the inner sealing mandrel 2530  
30 and the load mandrel 2550. The lower sealing head 2540 is also movably coupled to the inner surface of the outer sealing mandrel 2545. In this manner, the upper

WO 01/04535

PCT/US00/18635

sealing head 2535, outer sealing mandrel 2545, and expansion cone 2555 reciprocate in the axial direction.

The radial clearance between the outer surface of the lower sealing head 2540 and the inner surface of the outer sealing mandrel 2545 may range, for example, from about 0.0025 to 0.05 inches. In a preferred embodiment, the radial clearance between the outer surface of the lower sealing head 2540 and the inner surface of the outer sealing mandrel 2545 ranges from about 0.005 to 0.01 inches in order to optimally provide minimal radial clearance.

The lower sealing head 2540 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The lower sealing head 2540 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the lower sealing head 2540 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces. The outer surface of the lower sealing head 2540 preferably includes one or more annular sealing members 2635 for sealing the interface between the lower sealing head 2540 and the outer sealing mandrel 2545. The sealing members 2635 may comprise any number of conventional commercially available annular sealing members such as, for example, o-rings, polypak seals, or metal spring energized seals. In a preferred embodiment, the sealing members 2635 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

The lower sealing head 2540 may be coupled to the inner sealing mandrel 2530 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connections, oilfield country tubular goods specialty threaded connection, or a standard threaded connection. In a preferred embodiment, the lower sealing head 2540 is removably coupled to the inner sealing mandrel 2530 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the lower sealing head 2540 and the inner sealing mandrel 2530 includes one or more sealing members 2640 for fluidically sealing the interface between the lower sealing head 2540 and the inner sealing mandrel 2530.

The sealing members 2640 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2640 comprise polypak seals available from Parker Seals in order to  
5 optimally provide sealing for a long axial stroke.

The lower sealing head 2540 may be coupled to the load mandrel 2550 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, welding, amorphous bonding or a standard threaded  
10 connection. In a preferred embodiment, the lower sealing head 2540 is removably coupled to the load mandrel 2550 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the lower sealing head 2540 and the load mandrel 2550 includes one or more sealing members 2645 for fluidically sealing the interface between the lower sealing head 2540 and the load  
15 mandrel 2550. The sealing members 2645 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2645 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

20 In a preferred embodiment, the lower sealing head 2540 includes a throat passage 2650 fluidically coupled between the fluid passages 2590 and 2600. The throat passage 2650 is preferably of reduced size and is adapted to receive and engage with a plug 2655, or other similar device. In this manner, the fluid passage 2590 is fluidically isolated from the fluid passage 2600. In this manner, the pressure  
25 chamber 2660 is pressurized.

The outer sealing mandrel 2545 is coupled to the upper sealing head 2535 and the expansion cone 2555. The outer sealing mandrel 2545 is also movably coupled to the inner surface of the casing 2560 and the outer surface of the lower sealing head 2540. In this manner, the upper sealing head 2535, outer sealing  
30 mandrel 2545, and the expansion cone 2555 reciprocate in the axial direction. The radial clearance between the outer surface of the outer sealing mandrel 2545 and the inner surface of the casing 2560 may range, for example, from about 0.025 to

0.375 inches. In a preferred embodiment, the radial clearance between the outer surface of the outer sealing mandrel 2545 and the inner surface of the casing 2560 ranges from about 0.025 to 0.125 inches in order to optimally provide stabilization for the expansion cone 2535 during the expansion process. The radial clearance  
5 between the inner surface of the outer sealing mandrel 2545 and the outer surface of the lower sealing head 2540 may range, for example, from about 0.005 to 0.01 inches. In a preferred embodiment, the radial clearance between the inner surface of the outer sealing mandrel 2545 and the outer surface of the lower sealing head 2540 ranges from about 0.005 to 0.01 inches in order to optimally provide minimal  
10 radial clearance.

The outer sealing mandrel 2545 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The outer sealing mandrel 2545 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy  
15 steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the outer sealing mandrel 2545 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

The outer sealing mandrel 2545 may be coupled to the upper sealing head  
20 2535 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the outer sealing mandrel 2545 is removably coupled to the upper sealing head 2535 by a standard threaded  
25 connection. The outer sealing mandrel 2545 may be coupled to the expansion cone 2555 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the outer sealing mandrel 2545  
30 is removably coupled to the expansion cone 2555 by a standard threaded connection.

The upper sealing head 2535, the lower sealing head 2540, the inner sealing mandrel 2530, and the outer sealing mandrel 2545 together define a pressure chamber 2660. The pressure chamber 2660 is fluidically coupled to the passage 2590 via one or more passages 2595. During operation of the apparatus 2500, the plug  
5 2655 engages with the throat passage 2650 to fluidically isolate the fluid passage 2590 from the fluid passage 2600. The pressure chamber 2660 is then pressurized which in turn causes the upper sealing head 2535, outer sealing mandrel 2545, and expansion cone 2555 to reciprocate in the axial direction. The axial motion of the expansion cone 2555 in turn expands the casing 2560 in the radial direction.

10 The load mandrel 2550 is coupled to the lower sealing head 2540. The load mandrel 2550 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The load mandrel 2550 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel  
15 or other similar high strength materials. In a preferred embodiment, the load mandrel 2550 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

The load mandrel 2550 may be coupled to the lower sealing head 2540 using any number of conventional commercially available mechanical couplings such as,  
20 for example, oilfield country tubular goods, drillpipe connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the load mandrel 2550 is removably coupled to the lower sealing head 2540 by a standard threaded connection.

The load mandrel 2550 preferably includes a fluid passage 2600 that is  
25 adapted to convey fluidic materials from the fluid passage 2590 to the region outside of the apparatus 2500. In a preferred embodiment, the fluid passage 2600 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud, or lubricants at operating pressures and flow rates ranging, for example, from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

30 The expansion cone 2555 is coupled to the outer sealing mandrel 2545. The expansion cone 2555 is also movably coupled to the inner surface of the casing 2560. In this manner, the upper sealing head 2535, outer sealing mandrel 2545,

WO 01/04535

PCT/US00/18635

and the expansion cone 2555 reciprocate in the axial direction. The reciprocation of the expansion cone 2555 causes the casing 2560 to expand in the radial direction.

The expansion cone 2555 preferably comprises an annular member having

5 substantially cylindrical inner and conical outer surfaces. The outside radius of the outside conical surface may range, for example, from about 2 to 34 inches. In a preferred embodiment, the outside radius of the outside conical surface ranges from about 3 to 28 in order to optimally provide radial expansion for the widest variety of tubular casings. The axial length of the expansion cone 2555 may range,

10 for example, from about 2 to 8 times the largest outside diameter of the expansion cone 2535. In a preferred embodiment, the axial length of the expansion cone 2535 ranges from about 3 to 5 times the largest outside diameter of the expansion cone 2535 in order to optimally provide stabilization and centralization of the expansion cone 2535 during the expansion process. In a particularly preferred embodiment,

15 the maximum outside diameter of the expansion cone 2555 is between about 95 to 99 % of the inside diameter of the existing wellbore that the casing 2560 will be joined with. In a preferred embodiment, the angle of attack of the expansion cone 2555 ranges from about 5 to 30 degrees in order to optimally balance frictional forces and radial expansion forces. The optimum angle of attack of the expansion cone 2535 will vary as a function of the particular operational features of the expansion operation.

20

The expansion cone 2555 may be fabricated from any number of conventional commercially available materials such as, for example, machine tool steel, nitride steel, titanium, tungsten carbide, ceramics or other similar high

25 strength materials. In a preferred embodiment, the expansion cone 2555 is fabricated from D2 machine tool steel in order to optimally provide high strength, and resistance to wear and galling. In a particularly preferred embodiment, the outside surface of the expansion cone 2555 has a surface hardness ranging from about 58 to 62 Rockwell C in order to optimally provide high strength and wear

30 resistance.

The expansion cone 2555 may be coupled to the outside sealing mandrel 2545 using any number of conventional commercially available mechanical

WO 01/04535

PCT/US00/18635

couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding or a standard threaded connection. In a preferred embodiment, the expansion cone 2555 is coupled to the outside sealing mandrel 2545 using a standard threaded connection in order to

5 optimally provide high strength and easy replacement of the expansion cone 2555.

The casing 2560 is removably coupled to the slips 2525 and expansion cone 2555. The casing 2560 preferably comprises a tubular member. The casing 2560 may be fabricated from any number of conventional commercially available materials such as, for example, slotted tubulars, oilfield country tubular goods, low

10 alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the casing 2560 is fabricated from oilfield country tubular goods available from various foreign and domestic steel mills in order to

optimally provide high strength using standardized materials.

In a preferred embodiment, the upper end 2665 of the casing 2560 includes

15 a thin wall section 2670 and an outer annular sealing member 2675. In a preferred embodiment, the wall thickness of the thin wall section 2670 is about 50 to 100 % of the regular wall thickness of the casing 2560. In this manner, the upper end 2665 of the casing 2560 may be easily radially expanded and deformed into intimate contact with the lower end of an existing section of wellbore casing. In

20 a preferred embodiment, the lower end of the existing section of casing also includes a thin wall section. In this manner, the radial expansion of the thin walled section 2670 of casing 2560 into the thin walled section of the existing wellbore casing results in a wellbore casing having a substantially constant inside diameter.

The annular sealing member 2675 may be fabricated from any number of

25 conventional commercially available sealing materials such as, for example, epoxy, rubber, metal, or plastic. In a preferred embodiment, the annular sealing member 2675 is fabricated from StrataLock epoxy in order to optimally provide compressibility and resistance to wear. The outside diameter of the annular

30 sealing member 2675 preferably ranges from about 70 to 95 % of the inside diameter of the lower section of the wellbore casing that the casing 2560 is joined to. In this manner, after radial expansion, the annular sealing member 2670



WO 01/04535

PCT/US00/18635

optimally provides a fluidic seal and also preferably optimally provides sufficient frictional force with the inside surface of the existing section of wellbore casing during the radial expansion of the casing 2560 to support the casing 2560.

In a preferred embodiment, the lower end 2680 of the casing 2560 includes  
5 a thin wall section 2685 and an outer annular sealing member 2690. In a preferred embodiment, the wall thickness of the thin wall section 2685 is about 50 to 100 % of the regular wall thickness of the casing 2560. In this manner, the lower end 2680 of the casing 2560 may be easily expanded and deformed. Furthermore, in this manner, an other section of casing may be easily joined with the lower end  
10 2680 of the casing 2560 using a radial expansion process. In a preferred embodiment, the upper end of the other section of casing also includes a thin wall section. In this manner, the radial expansion of the thin walled section of the upper end of the other casing into the thin walled section 2685 of the lower end 2680 of the casing 2560 results in a wellbore casing having a substantially constant  
15 inside diameter.

The annular sealing member 2690 may be fabricated from any number of conventional commercially available sealing materials such as, for example, rubber, metal, plastic or epoxy. In a preferred embodiment, the annular sealing member 2690 is fabricated from StrataLock epoxy in order to optimally provide  
20 compressibility and resistance to wear. The outside diameter of the annular sealing member 2690 preferably ranges from about 70 to 95 % of the inside diameter of the lower section of the existing wellbore casing that the casing 2560 is joined to. In this manner, after radial expansion, the annular sealing member 2690 preferably provides a fluidic seal and also preferably provides sufficient  
25 frictional force with the inside wall of the wellbore during the radial expansion of the casing 2560 to support the casing 2560.

During operation, the apparatus 2500 is preferably positioned in a wellbore with the upper end 2665 of the casing 2560 positioned in an overlapping relationship with the lower end of an existing wellbore casing. In a particularly  
30 preferred embodiment, the thin wall section 2670 of the casing 2560 is positioned in opposing overlapping relation with the thin wall section and outer annular sealing member of the lower end of the existing section of wellbore casing. In this

WO 01/04535

PCT/US00/18635

manner, the radial expansion of the casing 2560 will compress the thin wall sections and annular compressible members of the upper end 2665 of the casing 2560 and the lower end of the existing wellbore casing into intimate contact. During the positioning of the apparatus 2500 in the wellbore, the casing 2560 is  
5 supported by the expansion cone 2555.

After positioning of the apparatus 2500, a first fluidic material is then pumped into the fluid passage 2565. The first fluidic material may comprise any number of conventional commercially available materials such as, for example, cement, water, slag-mix, epoxy or drilling mud. In a preferred embodiment, the  
10 first fluidic material comprises a hardenable fluidic sealing material such as, for example, cement, epoxy, or slag-mix in order to optimally provide a hardenable outer annular body around the expanded casing 2560.

The first fluidic material may be pumped into the fluid passage 2565 at operating pressures and flow rates ranging, for example, from about 0 to 4,500 psi  
15 and 0 to 3,000 gallons/minute. In a preferred embodiment, the first fluidic material is pumped into the fluid passage 2565 at operating pressures and flow rates ranging from about 0 to 3,500 psi and 0 to 1,200 gallons/minute in order to optimally provide operational efficiency.

The first fluidic material pumped into the fluid passage 2565 passes through  
20 the fluid passages 2570, 2575, 2580, 2590, 2600 and then outside of the apparatus 2500. The first fluidic material then preferably fills the annular region between the outside of the apparatus 2500 and the interior walls of the wellbore.

The plug 2655 is then introduced into the fluid passage 2565. The plug 2655 lodges in the throat passage 2650 and fluidically isolates and blocks off the fluid  
25 passage 2590. In a preferred embodiment, a couple of volumes of a non-hardenable fluidic material are then pumped into the fluid passage 2565 in order to remove any hardenable fluidic material contained within and to ensure that none of the fluid passages are blocked.

A second fluidic material is then pumped into the fluid passage 2565. The  
30 second fluidic material may comprise any number of conventional commercially available materials such as, for example, water, drilling gases, drilling mud or lubricant. In a preferred embodiment, the second fluidic material comprises a non-

WO 01/04535

PCT/US00/18635

hardenable fluidic material such as, for example, water, drilling mud, or lubricant in order to optimally provide pressurization of the pressure chamber 2660 and minimize friction.

5 The second fluidic material may be pumped into the fluid passage 2565 at operating pressures and flow rates ranging, for example, from about 0 to 4,500 psi and 0 to 4,500 gallons/minute. In a preferred embodiment, the second fluidic material is pumped into the fluid passage 2565 at operating pressures and flow rates ranging from about 0 to 3,500 psi and 0 to 1,200 gallons/minute in order to optimally provide operational efficiency.

10 The second fluidic material pumped into the fluid passage 2565 passes through the fluid passages 2570, 2575, 2580, 2590 and into the pressure chambers 2605 of the slips 2525, and into the pressure chamber 2660. Continued pumping of the second fluidic material pressurizes the pressure chambers 2605 and 2660.

15 The pressurization of the pressure chambers 2605 causes the slip members 2525 to expand in the radial direction and grip the interior surface of the casing 2560. The casing 2560 is then preferably maintained in a substantially stationary position.

20 The pressurization of the pressure chamber 2660 causes the upper sealing head 2535, outer sealing mandrel 2545 and expansion cone 2555 to move in an axial direction relative to the casing 2560. In this manner, the expansion cone 2555 will cause the casing 2560 to expand in the radial direction, beginning with the lower end 2685 of the casing 2560.

25 During the radial expansion process, the casing 2560 is prevented from moving in an upward direction by the slips 2525. A length of the casing 2560 is then expanded in the radial direction through the pressurization of the pressure chamber 2660. The length of the casing 2560 that is expanded during the expansion process will be proportional to the stroke length of the upper sealing head 2535, outer sealing mandrel 2545, and expansion cone 2555.

30 Upon the completion of a stroke, the operating pressure of the second fluidic material is reduced and the upper sealing head 2535, outer sealing mandrel 2545, and expansion cone 2555 drop to their rest positions with the casing 2560 supported by the expansion cone 2555. The position of the drillpipe 2505 is

preferably adjusted throughout the radial expansion process in order to maintain the overlapping relationship between the thin walled sections of the lower end of the existing wellbore casing and the upper end of the casing 2560. In a preferred embodiment, the stroking of the expansion cone 2555 is then repeated, as  
5 necessary, until the thin walled section 2670 of the upper end 2665 of the casing 2560 is expanded into the thin walled section of the lower end of the existing wellbore casing. In this manner, a wellbore casing is formed including two adjacent sections of casing having a substantially constant inside diameter. This process may then be repeated for the entirety of the wellbore to provide a wellbore  
10 casing thousands of feet in length having a substantially constant inside diameter.

In a preferred embodiment, during the final stroke of the expansion cone 2555, the slips 2525 are positioned as close as possible to the thin walled section 2670 of the upper end 2665 of the casing 2560 in order minimize slippage between the casing 2560 and the existing wellbore casing at the end of the radial expansion  
15 process. Alternatively, or in addition, the outside diameter of the annular sealing member 2675 is selected to ensure sufficient interference fit with the inside diameter of the lower end of the existing casing to prevent axial displacement of the casing 2560 during the final stroke. Alternatively, or in addition, the outside diameter of the annular sealing member 2690 is selected to provide an interference  
20 fit with the inside walls of the wellbore at an earlier point in the radial expansion process so as to prevent further axial displacement of the casing 2560. In this final alternative, the interference fit is preferably selected to permit expansion of the casing 2560 by pulling the expansion cone 2555 out of the wellbore, without having to pressurize the pressure chamber 2660.

25 During the radial expansion process, the pressurized areas of the apparatus 2500 are preferably limited to the fluid passages 2565, 2570, 2575, 2580, and 2590, the pressure chambers 2605 within the slips 2525, and the pressure chamber 2660. No fluid pressure acts directly on the casing 2560. This permits the use of operating pressures higher than the casing 2560 could normally withstand.

30 Once the casing 2560 has been completely expanded off of the expansion cone 2555, the remaining portions of the apparatus 2500 are removed from the

WO 01/04535

PCT/US00/18635

wellbore. In a preferred embodiment, the contact pressure between the deformed thin wall sections and compressible annular members of the lower end of the existing casing and the upper end 2665 of the casing 2560 ranges from about 400 to 10,000 psi in order to optimally support the casing 2560 using the existing  
5 wellbore casing.

In this manner, the casing 2560 is radially expanded into contact with an existing section of casing by pressurizing the interior fluid passages 2565, 2570, 2575, 2580, and 2590, the pressure chambers of the slips 2605 and the pressure chamber 2660 of the apparatus 2500.

10 In a preferred embodiment, as required, the annular body of hardenable fluidic material is then allowed to cure to form a rigid outer annular body about the expanded casing 2560. In the case where the casing 2560 is slotted, the cured fluidic material preferably permeates and envelops the expanded casing 2560. The resulting new section of wellbore casing includes the expanded casing 2560 and the  
15 rigid outer annular body. The overlapping joint between the pre-existing wellbore casing and the expanded casing 2560 includes the deformed thin wall sections and the compressible outer annular bodies. The inner diameter of the resulting combined wellbore casings is substantially constant. In this manner, a mono-diameter wellbore casing is formed. This process of expanding overlapping tubular  
20 members having thin wall end portions with compressible annular bodies into contact can be repeated for the entire length of a wellbore. In this manner, a mono-diameter wellbore casing can be provided for thousands of feet in a subterranean formation.

In a preferred embodiment, as the expansion cone 2555 nears the upper end  
25 2665 of the casing 2560, the operating pressure of the second fluidic material is reduced in order to minimize shock to the apparatus 2500. In an alternative embodiment, the apparatus 2500 includes a shock absorber for absorbing the shock created by the completion of the radial expansion of the casing 2560.

In a preferred embodiment, the reduced operating pressure of the second  
30 fluidic material ranges from about 100 to 1,000 psi as the expansion cone 2555 nears the end of the casing 2560 in order to optimally provide reduced axial movement and velocity of the expansion cone 2555. In a preferred embodiment,

the operating pressure of the second fluidic material is reduced during the return stroke of the apparatus 2500 to the range of about 0 to 500 psi in order minimize the resistance to the movement of the expansion cone 2555 during the return stroke. In a preferred embodiment, the stroke length of the apparatus 2500 ranges  
5 from about 10 to 45 feet in order to optimally provide equipments lengths that can be easily handled using typical oil well rigging equipment and also minimize the frequency at which apparatus 2500 must be re-stroked.

In an alternative embodiment, at least a portion of the upper sealing head 2535 includes an expansion cone for radially expanding the casing 2560 during  
10 operation of the apparatus 2500 in order to increase the surface area of the casing 2560 acted upon during the radial expansion process. In this manner, the operating pressures can be reduced.

Alternatively, the apparatus 2500 may be used to join a first section of pipeline to an existing section of pipeline. Alternatively, the apparatus 2500 may  
15 be used to directly line the interior of a wellbore with a casing, without the use of an outer annular layer of a hardenable material. Alternatively, the apparatus 2500 may be used to expand a tubular support member in a hole.

Referring now to Figures 19, 19a and 19b, another embodiment of an apparatus 2700 for expanding a tubular member will be described. The apparatus  
20 2700 preferably includes a drillpipe 2705, an innerstring adapter 2710, a sealing sleeve 2715, a first inner sealing mandrel 2720, a first upper sealing head 2725, a first lower sealing head 2730, a first outer sealing mandrel 2735, a second inner sealing mandrel 2740, a second upper sealing head 2745, a second lower sealing head 2750, a second outer sealing mandrel 2755, a load mandrel 2760, an  
25 expansion cone 2765, a mandrel launcher 2770, a mechanical slip body 2775, mechanical slips 2780, drag blocks 2785, casing 2790, and fluid passages 2795, 2800, 2805, 2810, 2815, 2820, 2825, and 2830.

The drillpipe 2705 is coupled to the innerstring adapter 2710. During operation of the apparatus 2700, the drillpipe 2705 supports the apparatus 2700.  
30 The drillpipe 2705 preferably comprises a substantially hollow tubular member or members. The drillpipe 2705 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular

WO 01/04535

PCT/US00/18635

goods, low alloy steel, carbon steel, stainless steel, or other similar high strength materials. In a preferred embodiment, the drillpipe 2705 is fabricated from coiled tubing in order to facilitate the placement of the apparatus 2700 in non-vertical wellbores. The drillpipe 2705 may be coupled to the innerstring adapter 2710  
5 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, or a standard threaded connection. In a preferred embodiment, the drillpipe 2705 is removably coupled to the innerstring adapter 2710 by a drillpipe connection in order to optimally provide high strength and easy  
10 disassembly.

The drillpipe 2705 preferably includes a fluid passage 2795 that is adapted to convey fluidic materials from a surface location into the fluid passage 2800. In a preferred embodiment, the fluid passage 2795 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud or lubricants  
15 at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The innerstring adapter 2710 is coupled to the drill string 2705 and the sealing sleeve 2715. The innerstring adapter 2710 preferably comprises a substantially hollow tubular member or members. The innerstring adapter 2710  
20 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the innerstring adapter 2710 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction  
25 surfaces.

The innerstring adapter 2710 may be coupled to the drill string 2705 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, or a standard threaded connection. In a preferred embodiment, the  
30 innerstring adapter 2710 is removably coupled to the drill pipe 2705 by a standard threaded connection in order to optimally provide high strength and easy disassembly. The innerstring adapter 2710 may be coupled to the sealing sleeve

2715 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection or a standard threaded connection. In a preferred embodiment, the innerstring adapter  
5 2710 is removably coupled to the sealing sleeve 2715 by a standard threaded connection.

The innerstring adapter 2710 preferably includes a fluid passage 2800 that is adapted to convey fluidic materials from the fluid passage 2795 into the fluid passage 2805. In a preferred embodiment, the fluid passage 2800 is adapted to  
10 convey fluidic materials such as, for example, cement, epoxy, water, drilling mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The sealing sleeve 2715 is coupled to the innerstring adapter 2710 and the first inner sealing mandrel 2720. The sealing sleeve 2715 preferably comprises a  
15 substantially hollow tubular member or members. The sealing sleeve 2715 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the sealing sleeve 2715 is fabricated from stainless steel in order to  
20 optimally provide high strength, corrosion resistance, and low friction surfaces.

The sealing sleeve 2715 may be coupled to the innerstring adapter 2710 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, welding, amorphous bonding, or a standard threaded  
25 connection. In a preferred embodiment, the sealing sleeve 2715 is removably coupled to the innerstring adapter 2710 by a standard threaded connector. The sealing sleeve 2715 may be coupled to the first inner sealing mandrel 2720 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type  
30 threaded connection, welding, amorphous bonding or a standard threaded connection. In a preferred embodiment, the sealing sleeve 2715 is removably coupled to the inner sealing mandrel 2720 by a standard threaded connection.



WO 01/04535

PCT/US00/18635

The sealing sleeve 2715 preferably includes a fluid passage 2802 that is adapted to convey fluidic materials from the fluid passage 2800 into the fluid passage 2805. In a preferred embodiment, the fluid passage 2802 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The first inner sealing mandrel 2720 is coupled to the sealing sleeve 2715 and the first lower sealing head 2730. The first inner sealing mandrel 2720 preferably comprises a substantially hollow tubular member or members. The first inner sealing mandrel 2720 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the first inner sealing mandrel 2720 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

The first inner sealing mandrel 2720 may be coupled to the sealing sleeve 2715 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection oilfield country tubular goods specialty threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the first inner sealing mandrel 2720 is removably coupled to the sealing sleeve 2715 by a standard threaded connection. The first inner sealing mandrel 2720 may be coupled to the first lower sealing head 2730 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the first inner sealing mandrel 2720 is removably coupled to the first lower sealing head 2730 by a standard threaded connection.

The first inner sealing mandrel 2720 preferably includes a fluid passage 2805 that is adapted to convey fluidic materials from the fluid passage 2802 into the fluid passage 2810. In a preferred embodiment, the fluid passage 2805 is adapted to convey fluidic materials such as, for example, cement, epoxy, water,

drilling mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The first upper sealing head 2725 is coupled to the first outer sealing mandrel 2735, the second upper sealing head 2745, the second outer sealing mandrel 2755, and the expansion cone 2765. The first upper sealing head 2725 is also movably coupled to the outer surface of the first inner sealing mandrel 2720 and the inner surface of the casing 2790. In this manner, the first upper sealing head 2725 reciprocates in the axial direction. The radial clearance between the inner cylindrical surface of the first upper sealing head 2725 and the outer surface of the first inner sealing mandrel 2720 may range, for example, from about 0.0025 to 0.05 inches. In a preferred embodiment, the radial clearance between the inner cylindrical surface of the first upper sealing head 2725 and the outer surface of the first inner sealing mandrel 2720 ranges from about 0.005 to 0.125 inches in order to optimally provide minimal radial clearance. The radial clearance between the outer cylindrical surface of the first upper sealing head 2725 and the inner surface of the casing 2790 may range, for example, from about 0.025 to 0.375 inches. In a preferred embodiment, the radial clearance between the outer cylindrical surface of the first upper sealing head 2725 and the inner surface of the casing 2790 ranges from about 0.025 to 0.125 inches in order to optimally provide stabilization for the expansion cone 2765 during the expansion process.

The first upper sealing head 2725 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The first upper sealing head 2725 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the first upper sealing head 2725 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance and low friction surfaces. The inner surface of the first upper sealing head 2725 preferably includes one or more annular sealing members 2835 for sealing the interface between the first upper sealing head 2725 and the first inner sealing mandrel 2720. The sealing members 2835 may comprise any number of conventional commercially available annular sealing members such as, for

WO 01/04535

PCT/US00/18635

example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2835 comprise polypak seals available from Parker Seals in order to optimally provide sealing for long axial strokes.

5 In a preferred embodiment, the first upper sealing head 2725 includes a shoulder 2840 for supporting the first upper sealing head 2725 on the first lower sealing head 2730.

The first upper sealing head 2725 may be coupled to the first outer sealing mandrel 2735 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country  
10 tubular goods specialty threaded connection, welding, amorphous bonding or a standard threaded connection. In a preferred embodiment, the first upper sealing head 2725 is removably coupled to the first outer sealing mandrel 2735 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the first upper sealing head 2725 and the first outer sealing  
15 mandrel 2735 includes one or more sealing members 2845 for fluidically sealing the interface between the first upper sealing head 2725 and the first outer sealing mandrel 2735. The sealing members 2845 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the  
20 sealing members 2845 comprise polypak seals available from Parker Seals in order to optimally provide sealing for long axial strokes.

The first lower sealing head 2730 is coupled to the first inner sealing mandrel 2720 and the second inner sealing mandrel 2740. The first lower sealing head 2730 is also movably coupled to the inner surface of the first outer sealing  
25 mandrel 2735. In this manner, the first upper sealing head 2725 and first outer sealing mandrel 2735 reciprocate in the axial direction. The radial clearance between the outer surface of the first lower sealing head 2730 and the inner surface of the first outer sealing mandrel 2735 may range, for example, from about 0.0025 to 0.05 inches. In a preferred embodiment, the radial clearance between  
30 the outer surface of the first lower sealing head 2730 and the inner surface of the first outer sealing mandrel 2735 ranges from about 0.005 to 0.01 inches in order to optimally provide minimal radial clearance.

WO 01/04535

PCT/US00/18635

The first lower sealing head 2730 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The first lower sealing head 2730 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the first lower sealing head 2730 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces. The outer surface of the first lower sealing head 2730 preferably includes one or more annular sealing members 2850 for sealing the interface between the first lower sealing head 2730 and the first outer sealing mandrel 2735. The sealing members 2850 may comprise any number of conventional commercially available annular sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2850 comprise polypak seals available from Parker Seals in order to optimally provide sealing for long axial strokes.

The first lower sealing head 2730 may be coupled to the first inner sealing mandrel 2720 using any number of conventional commercially available mechanical couplings such as, for example, oilfield country tubular goods specialty threaded connections, welding, amorphous bonding, or standard threaded connection. In a preferred embodiment, the first lower sealing head 2730 is removably coupled to the first inner sealing mandrel 2720 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the first lower sealing head 2730 and the first inner sealing mandrel 2720 includes one or more sealing members 2855 for fluidically sealing the interface between the first lower sealing head 2730 and the first inner sealing mandrel 2720. The sealing members 2855 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2855 comprise polypak seals available from Parker Seals in order to optimally provide sealing for long axial strokes.

The first lower sealing head 2730 may be coupled to the second inner sealing mandrel 2740 using any number of conventional commercially available

WO 01/04535

PCT/US00/18635

mechanical couplings such as, for example, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the lower sealing head 2730 is removably coupled to the second inner sealing mandrel 2740 by a standard threaded  
5 connection. In a preferred embodiment, the mechanical coupling between the first lower sealing head 2730 and the second inner sealing mandrel 2740 includes one or more sealing members 2860 for fluidically sealing the interface between the first lower sealing head 2730 and the second inner sealing mandrel 2740. The sealing members 2860 may comprise any number of conventional commercially available  
10 sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2860 comprise polypak seals available from Parker Seals in order to optimally provide sealing for long axial strokes.

The first outer sealing mandrel 2735 is coupled to the first upper sealing  
15 head 2725, the second upper sealing head 2745, the second outer sealing mandrel 2755, and the expansion cone 2765. The first outer sealing mandrel 2735 is also movably coupled to the inner surface of the casing 2790 and the outer surface of the first lower sealing head 2730. In this manner, the first upper sealing head 2725, first outer sealing mandrel 2735, second upper sealing head 2745, second  
20 outer sealing mandrel 2755, and the expansion cone 2765 reciprocate in the axial direction. The radial clearance between the outer surface of the first outer sealing mandrel 2735 and the inner surface of the casing 2790 may range, for example, from about 0.025 to 0.375 inches. In a preferred embodiment, the radial clearance between the outer surface of the first outer sealing mandrel 2735 and the inner  
25 surface of the casing 2790 ranges from about 0.025 to 0.125 inches in order to optimally provide stabilization for the expansion cone 2765 during the expansion process. The radial clearance between the inner surface of the first outer sealing mandrel 2735 and the outer surface of the first lower sealing head 2730 may range, for example, from about 0.0025 to 0.05 inches. In a preferred embodiment, the  
30 radial clearance between the inner surface of the first outer sealing mandrel 2735 and the outer surface of the first lower sealing head 2730 ranges from about 0.005 to 0.01 inches in order to optimally provide minimal radial clearance.

The outer sealing mandrel 1935 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The first outer sealing mandrel 2735 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the first outer sealing mandrel 2735 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

The first outer sealing mandrel 2735 may be coupled to the first upper sealing head 2725 using any number of conventional commercially available mechanical couplings such as, for example, oilfield country tubular goods, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the first outer sealing mandrel 2735 is removably coupled to the first upper sealing head 2725 by a standard threaded connection. The first outer sealing mandrel 2735 may be coupled to the second upper sealing head 2745 using any number of conventional commercially available mechanical couplings such as, for example, oilfield country tubular goods specialty threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the first outer sealing mandrel 2735 is removably coupled to the second upper sealing head 2745 by a standard threaded connection.

The second inner sealing mandrel 2740 is coupled to the first lower sealing head 2730 and the second lower sealing head 2750. The second inner sealing mandrel 2740 preferably comprises a substantially hollow tubular member or members. The second inner sealing mandrel 2740 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the second inner sealing mandrel 2740 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

The second inner sealing mandrel 2740 may be coupled to the first lower sealing head 2730 using any number of conventional commercially available mechanical couplings such as, for example, oilfield country tubular goods specialty

WO 01/04535

PCT/US00/18635

threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the second inner sealing mandrel 2740 is removably coupled to the first lower sealing head 2740 by a standard threaded connection. The mechanical coupling between the second inner sealing mandrel  
5 2740 and the first lower sealing head 2730 preferably includes sealing members 2860.

The second inner sealing mandrel 2740 may be coupled to the second lower sealing head 2750 using any number of conventional commercially available mechanical couplings such as, for example, oilfield country tubular goods specialty  
10 threaded connection, welding, amorphous bonding, or a standard threaded connection. In a preferred embodiment, the second inner sealing mandrel 2720 is removably coupled to the second lower sealing head 2750 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the second inner sealing mandrel 2740 and the second lower sealing head 2750  
15 includes one or more sealing members 2865. The sealing members 2865 may comprise any number of conventional commercially available seals such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2865 comprise polypak seals available from Parker Seals.

20 The second inner sealing mandrel 2740 preferably includes a fluid passage 2810 that is adapted to convey fluidic materials from the fluid passage 2805 into the fluid passage 2815. In a preferred embodiment, the fluid passage 2810 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud or lubricants at operating pressures and flow rates ranging from  
25 about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The second upper sealing head 2745 is coupled to the first upper sealing head 2725, the first outer sealing mandrel 2735, the second outer sealing mandrel 2755, and the expansion cone 2765. The second upper sealing head 2745 is also movably coupled to the outer surface of the second inner sealing mandrel 2740 and  
30 the inner surface of the casing 2790. In this manner, the second upper sealing head 2745 reciprocates in the axial direction. The radial clearance between the inner cylindrical surface of the second upper sealing head 2745 and the outer

surface of the second inner sealing mandrel 2740 may range, for example, from about 0.0025 to 0.05 inches. In a preferred embodiment, the radial clearance between the inner cylindrical surface of the second upper sealing head 2745 and the outer surface of the second inner sealing mandrel 2740 ranges from about 0.005 to 0.01 inches in order to optimally provide minimal radial clearance. The radial clearance between the outer cylindrical surface of the second upper sealing head 2745 and the inner surface of the casing 2790 may range, for example, from about 0.025 to .375 inches. In a preferred embodiment, the radial clearance between the outer cylindrical surface of the second upper sealing head 2745 and the inner surface of the casing 2790 ranges from about 0.025 to 0.125 inches in order to optimally provide stabilization for the expansion cone 2765 during the expansion process.

The second upper sealing head 2745 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The second upper sealing head 2745 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the second upper sealing head 2745 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces. The inner surface of the second upper sealing head 2745 preferably includes one or more annular sealing members 2870 for sealing the interface between the second upper sealing head 2745 and the second inner sealing mandrel 2740. The sealing members 2870 may comprise any number of conventional commercially available annular sealing members such as, for example, o-rings, polypak seals, or metal spring energized seals. In a preferred embodiment, the sealing members 2870 comprise polypak seals available from Parker Seals in order to optimally provide sealing for long axial strokes.

In a preferred embodiment, the second upper sealing head 2745 includes a shoulder 2875 for supporting the second upper sealing head 2745 on the second lower sealing head 2750.

The second upper sealing head 2745 may be coupled to the first outer sealing mandrel 2735 using any number of conventional commercially available



WO 01/04535

PCT/US00/18635

mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, ratchet-latch type threaded connection, or a standard threaded connection. In a preferred embodiment, the second upper sealing head 2745 is removably coupled to the first outer sealing mandrel 2735 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the second upper sealing head 2745 and the first outer sealing mandrel 2735 includes one or more sealing members 2880 for fluidically sealing the interface between the second upper sealing head 2745 and the first outer sealing mandrel 2735. The sealing members 2880 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2880 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

The second upper sealing head 2745 may be coupled to the second outer sealing mandrel 2755 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, or a standard threaded connection. In a preferred embodiment, the second upper sealing head 2745 is removably coupled to the second outer sealing mandrel 2755 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the second upper sealing head 2745 and the second outer sealing mandrel 2755 includes one or more sealing members 2885 for fluidically sealing the interface between the second upper sealing head 2745 and the second outer sealing mandrel 2755. The sealing members 2885 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2885 comprise polypak seals available from Parker Seals in order to optimally provide sealing for long axial strokes.

The second lower sealing head 2750 is coupled to the second inner sealing mandrel 2740 and the load mandrel 2760. The second lower sealing head 2750 is also movably coupled to the inner surface of the second outer sealing mandrel 2755. In this manner, the first upper sealing head 2725, the first outer sealing

WO 01/04535

PCT/US00/18635

mandrel 2735, second upper sealing head 2745, second outer sealing mandrel 2755, and the expansion cone 2765 reciprocate in the axial direction. The radial clearance between the outer surface of the second lower sealing head 2750 and the inner surface of the second outer sealing mandrel 2755 may range, for example, 5 from about 0.0025 to 0.05 inches. In a preferred embodiment, the radial clearance between the outer surface of the second lower sealing head 2750 and the inner surface of the second outer sealing mandrel 2755 ranges from about 0.005 to 0.01 inches in order to optimally provide minimal radial clearance.

The second lower sealing head 2750 preferably comprises an annular 10 member having substantially cylindrical inner and outer surfaces. The second lower sealing head 2750 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the second lower sealing head 2750 is 15 fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces. The outer surface of the second lower sealing head 2750 preferably includes one or more annular sealing members 2890 for sealing the interface between the second lower sealing head 2750 and the second outer sealing mandrel 2755. The sealing members 2890 may comprise any 20 number of conventional commercially available annular sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2890 comprise polypak seals available from Parker Seals in order to optimally provide sealing for long axial strokes.

The second lower sealing head 2750 may be coupled to the second inner 25 sealing mandrel 2740 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, ratchet-latch type threaded connection, or a standard threaded connection. In a preferred embodiment, the second lower sealing head 2750 is removably coupled to the second inner sealing 30 mandrel 2740 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the second lower sealing head 2750 and the second inner sealing mandrel 2740 includes one or more sealing members 2895 for

WO 01/04535

PCT/US00/18635

fluidically sealing the interface between the second sealing head 2750 and the second sealing mandrel 2740. The sealing members 2895 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the  
5 sealing members 2895 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

The second lower sealing head 2750 may be coupled to the load mandrel 2760 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield tubular goods specialty  
10 threaded connection, ratchet-latch type threaded connection, or a standard threaded connection. In a preferred embodiment, the second lower sealing head 2750 is removably coupled to the load mandrel 2760 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the second lower sealing head 2750 and the load mandrel 2760 includes one or more  
15 sealing members 2900 for fluidically sealing the interface between the second lower sealing head 2750 and the load mandrel 2760. The sealing members 2900 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 2900 comprise polypak seals available  
20 from Parker Seals in order to optimally provide sealing for long axial strokes.

In a preferred embodiment, the second lower sealing head 2750 includes a throat passage 2905 fluidically coupled between the fluid passages 2810 and 2815. The throat passage 2905 is preferably of reduced size and is adapted to receive and engage with a plug 2910, or other similar device. In this manner, the fluid passage  
25 2810 is fluidically isolated from the fluid passage 2815. In this manner, the pressure chambers 2915 and 2920 are pressurized. The use of a plurality of pressure chambers in the apparatus 2700 permits the effective driving force to be multiplied. While illustrated using a pair of pressure chambers, 2915 and 2920, the apparatus 2700 may be further modified to employ additional pressure  
30 chambers.

The second outer sealing mandrel 2755 is coupled to the first upper sealing head 2725, the first outer sealing mandrel 2735, the second upper sealing head

WO 01/04535

PCT/US00/18635

2745, and the expansion cone 2765. The second outer sealing mandrel 2755 is also movably coupled to the inner surface of the casing 2790 and the outer surface of the second lower sealing head 2750. In this manner, the first upper sealing head 2725, first outer sealing mandrel 2735, second upper sealing head 2745, second  
5 outer sealing mandrel 2755, and the expansion cone 2765 reciprocate in the axial direction.

The radial clearance between the outer surface of the second outer sealing mandrel 2755 and the inner surface of the casing 2790 may range, for example, from about 0.025 to 0.375 inches. In a preferred embodiment, the radial clearance  
10 between the outer surface of the second outer sealing mandrel 2755 and the inner surface of the casing 2790 ranges from about 0.025 to 0.125 inches in order to optimally provide stabilization for the expansion cone 2765 during the expansion process. The radial clearance between the inner surface of the second outer sealing mandrel 2755 and the outer surface of the second lower sealing head 2750 may  
15 range, for example, from about 0.0025 to 0.05 inches. In a preferred embodiment, the radial clearance between the inner surface of the second outer sealing mandrel 2755 and the outer surface of the second lower sealing head 2750 ranges from about 0.005 to 0.01 inches in order to optimally provide minimal radial clearance.

The second outer sealing mandrel 2755 preferably comprises an annular  
20 member having substantially cylindrical inner and outer surfaces. The second outer sealing mandrel 2755 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the second outer sealing mandrel 2755 is  
25 fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

The second outer sealing mandrel 2755 may be coupled to the second upper sealing head 2745 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country  
30 tubular goods specialty threaded connection, ratchet-latch type threaded connection or a standard threaded connection. In a preferred embodiment, the second outer sealing mandrel 2755 is removably coupled to the second upper

WO 01/04535

PCT/US00/18635

sealing head 2745 by a standard threaded connection. The second outer sealing mandrel 2755 may be coupled to the expansion cone 2765 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection, or a standard threaded connection. In a preferred embodiment, the second outer sealing mandrel 2755 is removably coupled to the expansion cone 2765 by a standard threaded connection.

The load mandrel 2760 is coupled to the second lower sealing head 2750 and the mechanical slip body 2755. The load mandrel 2760 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The load mandrel 2760 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the load mandrel 2760 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

The load mandrel 2760 may be coupled to the second lower sealing head 2750 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection, or a standard threaded connection. In a preferred embodiment, the load mandrel 2760 is removably coupled to the second lower sealing head 2750 by a standard threaded connection. The load mandrel 2760 may be coupled to the mechanical slip body 2775 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection or a standard threaded connection. In a preferred embodiment, the load mandrel 2760 is removably coupled to the mechanical slip body 2775 by a standard threaded connection.

The load mandrel 2760 preferably includes a fluid passage 2815 that is adapted to convey fluidic materials from the fluid passage 2810 to the fluid passage 2820. In a preferred embodiment, the fluid passage 2815 is adapted to convey

fluidic materials such as, for example, cement, epoxy, water, drilling mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The expansion cone 2765 is coupled to the second outer sealing mandrel  
5 2755. The expansion cone 2765 is also movably coupled to the inner surface of the casing 2790. In this manner, the first upper sealing head 2725, first outer sealing mandrel 2735, second upper sealing head 2745, second outer sealing mandrel 2755, and the expansion cone 2765 reciprocate in the axial direction. The reciprocation of the expansion cone 2765 causes the casing 2790 to expand in the radial  
10 direction.

The expansion cone 2765 preferably comprises an annular member having substantially cylindrical inner and conical outer surfaces. The outside radius of the outside conical surface may range, for example, from about 2 to 34 inches. In a preferred embodiment, the outside radius of the outside conical surface ranges  
15 from about 3 to 28 inches in order to optimally provide expansion cone dimensions that accommodate the typical range of casings. The axial length of the expansion cone 2765 may range, for example, from about 2 to 8 times the largest outer diameter of the expansion cone 2765. In a preferred embodiment, the axial length of the expansion cone 2765 ranges from about 3 to 5 times the largest outer  
20 diameter of the expansion cone 2765 in order to optimally provide stabilization and centralization of the expansion cone 2765. In a preferred embodiment, the angle of attack of the expansion cone 2765 ranges from about 5 to 30 degrees in order to optimally balance frictional forces and radial expansion forces.

The expansion cone 2765 may be fabricated from any number of  
25 conventional commercially available materials such as, for example, machine tool steel, nitride steel, titanium, tungsten carbide, ceramics or other similar high strength materials. In a preferred embodiment, the expansion cone 2765 is fabricated from D2 machine tool steel in order to optimally provide high strength and resistance to corrosion and galling. In a particularly preferred embodiment,  
30 the outside surface of the expansion cone 2765 has a surface hardness ranging from about 58 to 62 Rockwell C in order to optimally provide high strength and resistance to wear and galling.

WO 01/04535

PCT/US00/18635

The expansion cone 2765 may be coupled to the second outside sealing mandrel 2765 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded  
5 connection or a standard threaded connection. In a preferred embodiment, the expansion cone 2765 is coupled to the second outside sealing mandrel 2765 using a standard threaded connection in order to optimally provide high strength and easy replacement of the expansion cone 2765.

The mandrel launcher 2770 is coupled to the casing 2790. The mandrel  
10 launcher 2770 comprises a tubular section of casing having a reduced wall thickness compared to the casing 2790. In a preferred embodiment, the wall thickness of the mandrel launcher 2770 is about 50 to 100 % of the wall thickness of the casing 2790. The wall thickness of the mandrel launcher 2770 may range, for example, from about 0.15 to 1.5 inches. In a preferred embodiment, the wall  
15 thickness of the mandrel launcher 2770 ranges from about 0.25 to 0.75 inches. In this manner, the initiation of the radial expansion of the casing 2790 is facilitated, the placement of the apparatus 2700 within a wellbore casing and wellbore is facilitated, and the mandrel launcher 2770 has a burst strength approximately equal to that of the casing 2790.

20 The mandrel launcher 2770 may be coupled to the casing 2790 using any number of conventional mechanical couplings such as, for example, a standard threaded connection. The mandrel launcher 2770 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel, or other  
25 similar high strength materials. In a preferred embodiment, the mandrel launcher 2770 is fabricated from oilfield country tubular goods of higher strength than that of the casing 2790 but with a reduced wall thickness in order to optimally provide a small compact tubular container having a burst strength approximately equal to that of the casing 2790.

30 The mechanical slip body 2775 is coupled to the load mandrel 2760, the mechanical slips 2780, and the drag blocks 2785. The mechanical slip body 2775 preferably comprises a tubular member having an inner passage 2820 fluidly

WO 01/04535

PCT/US00/18635

coupled to the passage 2815. In this manner, fluidic materials may be conveyed from the passage 2820 to a region outside of the apparatus 2700.

The mechanical slip body 2775 may be coupled to the load mandrel 2760 using any number of conventional mechanical couplings. In a preferred embodiment, the mechanical slip body 2775 is removably coupled to the load mandrel 2760 using a standard threaded connection in order to optimally provide high strength and easy disassembly. The mechanical slip body 2775 may be coupled to the mechanical slips 2780 using any number of conventional mechanical couplings. In a preferred embodiment, the mechanical slip body 2755 is removably coupled to the mechanical slips 2780 using threaded connections and sliding steel retainer rings in order to optimally provide a high strength attachment. The mechanical slip body 2755 may be coupled to the drag blocks 2785 using any number of conventional mechanical couplings. In a preferred embodiment, the mechanical slip body 2775 is removably coupled to the drag blocks 2785 using threaded connections and sliding steel retainer rings in order to optimally provide a high strength attachment.

The mechanical slip body 2775 preferably includes a fluid passage 2820 that is adapted to convey fluidic materials from the fluid passage 2815 to the region outside of the apparatus 2700. In a preferred embodiment, the fluid passage 2820 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The mechanical slips 2780 are coupled to the outside surface of the mechanical slip body 2775. During operation of the apparatus 2700, the mechanical slips 2780 prevent upward movement of the casing 2790 and mandrel launcher 2770. In this manner, during the axial reciprocation of the expansion cone 2765, the casing 2790 and mandrel launcher 2770 are maintained in a substantially stationary position. In this manner, the mandrel launcher 2765 and casing 2790 and mandrel launcher 2770 are expanded in the radial direction by the axial movement of the expansion cone 2765.

The mechanical slips 2780 may comprise any number of conventional commercially available mechanical slips such as, for example, RTTS packer



WO 01/04535

PCT/US00/18635

tungsten carbide mechanical slips, RTTS packer wicker type mechanical slips or Model 3L retrievable bridge plug tungsten carbide upper mechanical slips. In a preferred embodiment, the mechanical slips 2780 comprise RTTS packer tungsten carbide mechanical slips available from Halliburton Energy Services in order to  
5 optimally provide resistance to axial movement of the casing 2790 and mandrel launcher 2770 during the expansion process.

The drag blocks 2785 are coupled to the outside surface of the mechanical slip body 2775. During operation of the apparatus 2700, the drag blocks 2785 prevent upward movement of the casing 2790 and mandrel launcher 2770. In this  
10 manner, during the axial reciprocation of the expansion cone 2765, the casing 2790 and mandrel launcher 2770 are maintained in a substantially stationary position. In this manner, the mandrel launcher 2770 and casing 2790 are expanded in the radial direction by the axial movement of the expansion cone 2765.

The drag blocks 2785 may comprise any number of conventional  
15 commercially available mechanical slips such as, for example, RTTS packer mechanical drag blocks or Model 3L retrievable bridge plug drag blocks. In a preferred embodiment, the drag blocks 2785 comprise RTTS packer mechanical drag blocks available from Halliburton Energy Services in order to optimally provide resistance to axial movement of the casing 2790 and mandrel launcher  
20 2770 during the expansion process.

The casing 2790 is coupled to the mandrel launcher 2770. The casing 2790 is further removably coupled to the mechanical slips 2780 and drag blocks 2785. The casing 2790 preferably comprises a tubular member. The casing 2790 may be fabricated from any number of conventional commercially available materials such  
25 as, for example, slotted tubulars, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the casing 2790 is fabricated from oilfield country tubular goods available from various foreign and domestic steel mills in order to optimally provide high strength using standardized materials. In a preferred embodiment,  
30 the upper end of the casing 2790 includes one or more sealing members positioned about the exterior of the casing 2790.

WO 01/04535

PCT/US00/18635

During operation, the apparatus 2700 is positioned in a wellbore with the upper end of the casing 2790 positioned in an overlapping relationship within an existing wellbore casing. In order minimize surge pressures within the borehole during placement of the apparatus 2700, the fluid passage 2795 is preferably  
5 provided with one or more pressure relief passages. During the placement of the apparatus 2700 in the wellbore, the casing 2790 is supported by the expansion cone 2765.

After positioning of the apparatus 2700 within the bore hole in an overlapping relationship with an existing section of wellbore casing, a first fluidic  
10 material is pumped into the fluid passage 2795 from a surface location. The first fluidic material is conveyed from the fluid passage 2795 to the fluid passages 2800, 2802, 2805, 2810, 2815, and 2820. The first fluidic material will then exit the apparatus 2700 and fill the annular region between the outside of the apparatus 2700 and the interior walls of the bore hole.

15 The first fluidic material may comprise any number of conventional commercially available materials such as, for example, epoxy, drilling mud, slag mix, water or cement. In a preferred embodiment, the first fluidic material comprises a hardenable fluidic sealing material such as, for example, slag mix, epoxy, or cement. In this manner, a wellbore casing having an outer annular layer  
20 of a hardenable material may be formed.

The first fluidic material may be pumped into the apparatus 2700 at operating pressures and flow rates ranging, for example, from about 0 to 4,500 psi and 0 to 3,000 gallons/minute. In a preferred embodiment, the first fluidic  
25 material is pumped into the apparatus 2700 at operating pressures and flow rates ranging from about 0 to 3,500 psi and 0 to 1,200 gallons/minute in order to optimally provide operational efficiency.

At a predetermined point in the injection of the first fluidic material such as, for example, after the annular region outside of the apparatus 2700 has been filled to a predetermined level, a plug 2910, dart, or other similar device is  
30 introduced into the first fluidic material. The plug 2910 lodges in the throat passage 2905 thereby fluidically isolating the fluid passage 2810 from the fluid passage 2815.

WO 01/04535

PCT/US00/18635

After placement of the plug 2910 in the throat passage 2905, a second fluidic material is pumped into the fluid passage 2795 in order to pressurize the pressure chambers 2915 and 2920. The second fluidic material may comprise any number of conventional commercially available materials such as, for example, water, drilling gases, drilling mud or lubricants. In a preferred embodiment, the second fluidic material comprises a non-hardenable fluidic material such as, for example, water, drilling mud or lubricant. The use of lubricant optimally provides lubrication of the moving parts of the apparatus 2700.

The second fluidic material may be pumped into the apparatus 2700 at operating pressures and flow rates ranging, for example, from about 0 to 4,500 psi and 0 to 4,500 gallons/minute. In a preferred embodiment, the second fluidic material is pumped into the apparatus 2700 at operating pressures and flow rates ranging from about 0 to 3,500 psi and 0 to 1,200 gallons/minute in order to optimally provide operational efficiency.

The pressurization of the pressure chambers 2915 and 2920 cause the upper sealing heads, 2725 and 2745, outer sealing mandrels, 2735 and 2755, and expansion cone 2765 to move in an axial direction. As the expansion cone 2765 moves in the axial direction, the expansion cone 2765 pulls the mandrel launcher 2770, casing 2790, and drag blocks 2785 along, which sets the mechanical slips 2780 and stops further axial movement of the mandrel launcher 2770 and casing 2790. In this manner, the axial movement of the expansion cone 2765 radially expands the mandrel launcher 2770 and casing 2790.

Once the upper sealing heads, 2725 and 2745, outer sealing mandrels, 2735 and 2755, and expansion cone 2765 complete an axial stroke, the operating pressure of the second fluidic material is reduced and the drill string 2705 is raised. This causes the inner sealing mandrels, 2720 and 2740, lower sealing heads, 2730 and 2750, load mandrel 2760, and mechanical slip body 2755 to move upward. This unsets the mechanical slips 2780 and permits the mechanical slips 2780 and drag blocks 2785 to be moved upward within the mandrel launcher 2770 and casing 2790. When the lower sealing heads, 2730 and 2750, contact the upper sealing heads, 2725 and 2745, the second fluidic material is again pressurized and the radial expansion process continues. In this manner, the mandrel launcher

2770 and casing 2790 are radially expanded through repeated axial strokes of the upper sealing heads, 2725 and 2745, outer sealing mandrels, 2735 and 2755, and expansion cone 2765. Throughout the radial expansion process, the upper end of the casing 2790 is preferably maintained in an overlapping relation with an  
5 existing section of wellbore casing.

At the end of the radial expansion process, the upper end of the casing 2790 is expanded into intimate contact with the inside surface of the lower end of the existing wellbore casing. In a preferred embodiment, the sealing members provided at the upper end of the casing 2790 provide a fluidic seal between the  
10 outside surface of the upper end of the casing 2790 and the inside surface of the lower end of the existing wellbore casing. In a preferred embodiment, the contact pressure between the casing 2790 and the existing section of wellbore casing ranges from about 400 to 10,000 in order to optimally provide contact pressure for activating the sealing members, provide optimal resistance to axial movement of  
15 the expanded casing, and optimally resist typical tensile and compressive loads on the expanded casing.

In a preferred embodiment, as the expansion cone 2765 nears the end of the casing 2790, the operating pressure of the second fluidic material is reduced in order to minimize shock to the apparatus 2700. In an alternative embodiment, the  
20 apparatus 2700 includes a shock absorber for absorbing the shock created by the completion of the radial expansion of the casing 2790.

In a preferred embodiment, the reduced operating pressure of the second fluidic material ranges from about 100 to 1,000 psi as the expansion cone 2765 nears the end of the casing 2790 in order to optimally provide reduced axial  
25 movement and velocity of the expansion cone 2765. In a preferred embodiment, the operating pressure of the second fluidic material is reduced during the return stroke of the apparatus 2700 to the range of about 0 to 500 psi in order minimize the resistance to the movement of the expansion cone 2765 during the return stroke. In a preferred embodiment, the stroke length of the apparatus 2700 ranges  
30 from about 10 to 45 feet in order to optimally provide equipment that can be easily handled by typical oil well rigging equipment and minimize the frequency at which the apparatus 2700 must be re-stroked during an expansion operation.

WO 01/04535

PCT/US00/18635

In an alternative embodiment, at least a portion of the upper sealing heads, 2725 and 2745, include expansion cones for radially expanding the mandrel launcher 2770 and casing 2790 during operation of the apparatus 2700 in order to increase the surface area of the casing 2790 acted upon during the radial expansion process. In this manner, the operating pressures can be reduced.

In an alternative embodiment, mechanical slips are positioned in an axial location between the sealing sleeve 1915 and the first inner sealing mandrel 2720 in order to optimally provide a simplified assembly and operation of the apparatus 2700.

10        Upon the complete radial expansion of the casing 2790, if applicable, the first fluidic material is permitted to cure within the annular region between the outside of the expanded casing 2790 and the interior walls of the wellbore. In the case where the casing 2790 is slotted, the cured fluidic material preferably permeates and envelops the expanded casing 2790. In this manner, a new section  
15 of wellbore casing is formed within a wellbore. Alternatively, the apparatus 2700 may be used to join a first section of pipeline to an existing section of pipeline. Alternatively, the apparatus 2700 may be used to directly line the interior of a wellbore with a casing, without the use of an outer annular layer of a hardenable material. Alternatively, the apparatus 2700 may be used to expand a tubular  
20 support member in a hole.

During the radial expansion process, the pressurized areas of the apparatus 2700 are limited to the fluid passages 2795, 2800, 2802, 2805, and 2810, and the pressure chambers 2915 and 2920. No fluid pressure acts directly on the mandrel launcher 2770 and casing 2790. This permits the use of operating pressures higher  
25 than the mandrel launcher 2770 and casing 2790 could normally withstand.

Referring now to Figure 20, a preferred embodiment of an apparatus 3000 for forming a mono-diameter wellbore casing will be described. The apparatus 3000 preferably includes a drillpipe 3005, an innerstring adapter 3010, a sealing sleeve 3015, a first inner sealing mandrel 3020, hydraulic slips 3025, a first upper  
30 sealing head 3030, a first lower sealing head 3035, a first outer sealing mandrel 3040, a second inner sealing mandrel 3045, a second upper sealing head 3050, a second lower sealing head 3055, a second outer sealing mandrel 3060, load mandrel

WO 01/04535

PCT/US00/18635

3065, expansion cone 3070, casing 3075, and fluid passages 3080, 3085, 3090, 3095, 3100, 3105, 3110, 3115 and 3120.

The drillpipe 3005 is coupled to the innerstring adapter 3010. During operation of the apparatus 3000, the drillpipe 3005 supports the apparatus 3000.

- 5 The drillpipe 3005 preferably comprises a substantially hollow tubular member or members. The drillpipe 3005 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the drillpipe 3005 is fabricated from coiled
- 10 tubing in order to facilitate the placement of the apparatus 3000 in non-vertical wellbores. The drillpipe 3005 may be coupled to the innerstring adapter 3010 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty threaded connection, or a standard threaded connection. In a preferred
- 15 embodiment, the drillpipe 3005 is removably coupled to the innerstring adapter 3010 by a drillpipe connection.

- The drillpipe 3005 preferably includes a fluid passage 3080 that is adapted to convey fluidic materials from a surface location into the fluid passage 3085. In a preferred embodiment, the fluid passage 3080 is adapted to convey fluidic
- 20 materials such as, for example, cement, epoxy, water, drilling mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

- The innerstring adapter 3010 is coupled to the drill string 3005 and the sealing sleeve 3015. The innerstring adapter 3010 preferably comprises a
- 25 substantially hollow tubular member or members. The innerstring adapter 3010 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel, or other similar high strength materials. In a preferred embodiment, the innerstring adapter 3010 is fabricated from stainless
- 30 steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

WO 01/04535

PCT/US00/18635

The innerstring adapter 3010 may be coupled to the drill string 3005 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, or a standard threaded connection. In a preferred embodiment, the innerstring adapter 3010 is removably coupled to the drill pipe 3005 by a drillpipe connection. The innerstring adapter 3010 may be coupled to the sealing sleeve 3015 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection or a standard threaded connection. In a preferred embodiment, the innerstring adapter 3010 is removably coupled to the sealing sleeve 3015 by a standard threaded connection.

The innerstring adapter 3010 preferably includes a fluid passage 3085 that is adapted to convey fluidic materials from the fluid passage 3080 into the fluid passage 3090. In a preferred embodiment, the fluid passage 3085 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud, or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The sealing sleeve 3015 is coupled to the innerstring adapter 3010 and the first inner sealing mandrel 3020. The sealing sleeve 3015 preferably comprises a substantially hollow tubular member or members. The sealing sleeve 3015 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the sealing sleeve 3015 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

The sealing sleeve 3015 may be coupled to the innerstring adapter 3010 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type connection or a standard threaded connection. In a preferred embodiment, the sealing sleeve 3015 is removably coupled to the innerstring adapter 3010 by a standard threaded connection. The

WO 01/04535

PCT/US00/18635

sealing sleeve 3015 may be coupled to the first inner sealing mandrel 3020 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection or a standard  
5 threaded connection. In a preferred embodiment, the sealing sleeve 3015 is removably coupled to the first inner sealing mandrel 3020 by a standard threaded connection.

The sealing sleeve 3015 preferably includes a fluid passage 3090 that is adapted to convey fluidic materials from the fluid passage 3085 into the fluid  
10 passage 3095. In a preferred embodiment, the fluid passage 3090 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud, or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The first inner sealing mandrel 3020 is coupled to the sealing sleeve 3015,  
15 the hydraulic slips 3025, and the first lower sealing head 3035. The first inner sealing mandrel 3020 is further movably coupled to the first upper sealing head 3030. The first inner sealing mandrel 3020 preferably comprises a substantially hollow tubular member or members. The first inner sealing mandrel 3020 may be fabricated from any number of conventional commercially available materials such  
20 as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel, or similar high strength materials. In a preferred embodiment, the first inner sealing mandrel 3020 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

The first inner sealing mandrel 3020 may be coupled to the sealing sleeve  
25 3015 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection or a standard threaded connection. In a preferred embodiment, the first inner sealing mandrel 3020 is removably coupled to the sealing sleeve 3015 by a standard  
30 threaded connection. The first inner sealing mandrel 3020 may be coupled to the hydraulic slips 3025 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country



WO 01/04535

PCT/US00/18635

tubular goods specialty type threaded connection, ratchet-latch type threaded connection or a standard threaded connection. In a preferred embodiment, the first inner sealing mandrel 3020 is removably coupled to the hydraulic slips 3025 by a standard threaded connection. The first inner sealing mandrel 3020 may be coupled to the first lower sealing head 3035 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection or a standard threaded connection. In a preferred embodiment, the first inner sealing mandrel 3020 is removably coupled to the first lower sealing head 3035 by a standard threaded connection.

The first inner sealing mandrel 3020 preferably includes a fluid passage 3095 that is adapted to convey fluidic materials from the fluid passage 3090 into the fluid passage 3100. In a preferred embodiment, the fluid passage 3095 is adapted to convey fluidic materials such as, for example, water, drilling mud, cement, epoxy, or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The first inner sealing mandrel 3020 further preferably includes fluid passages 3110 that are adapted to convey fluidic materials from the fluid passage 3095 into the pressure chambers of the hydraulic slips 3025. In this manner, the slips 3025 are activated upon the pressurization of the fluid passage 3095 into contact with the inside surface of the casing 3075. In a preferred embodiment, the fluid passages 3110 are adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling fluids or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The first inner sealing mandrel 3020 further preferably includes fluid passages 3115 that are adapted to convey fluidic materials from the fluid passage 3095 into the first pressure chamber 3175 defined by the first upper sealing head 3030, the first lower sealing head 3035, the first inner sealing mandrel 3020, and the first outer sealing mandrel 3040. During operation of the apparatus 3000, pressurization of the pressure chamber 3175 causes the first upper sealing head 3030, the first outer sealing mandrel 3040, the second upper sealing head 3050, the

WO 01/04535

PCT/US00/18635

second outer sealing mandrel 3060, and the expansion cone 3070 to move in an axial direction.

The slips 3025 are coupled to the outside surface of the first inner sealing mandrel 3020. During operation of the apparatus 3000, the slips 3025 are  
5 activated upon the pressurization of the fluid passage 3095 into contact with the inside surface of the casing 3075. In this manner, the slips 3025 maintain the casing 3075 in a substantially stationary position.

The slips 3025 preferably include fluid passages 3125, pressure chambers 3130, spring bias 3135, and slip members 3140. The slips 3025 may comprise any  
10 number of conventional commercially available hydraulic slips such as, for example, RTTS packer tungsten carbide hydraulic slips or Model 3L retrievable bridge plug with hydraulic slips. In a preferred embodiment, the slips 3025 comprise RTTS packer tungsten carbide hydraulic slips available from Halliburton Energy Services in order to optimally provide resistance to axial movement of the  
15 casing 3075 during the expansion process.

The first upper sealing head 3030 is coupled to the first outer sealing mandrel 3040, the second upper sealing head 3050, the second outer sealing mandrel 3060, and the expansion cone 3070. The first upper sealing head 3030 is also movably coupled to the outer surface of the first inner sealing mandrel 3020  
20 and the inner surface of the casing 3075. In this manner, the first upper sealing head 3030, the first outer sealing mandrel 3040, the second upper sealing head 3050, the second outer sealing mandrel 3060, and the expansion cone 3070 reciprocate in the axial direction.

The radial clearance between the inner cylindrical surface of the first upper  
25 sealing head 3030 and the outer surface of the first inner sealing mandrel 3020 may range, for example, from about 0.0025 to 0.05 inches. In a preferred embodiment, the radial clearance between the inner cylindrical surface of the first upper sealing head 3030 and the outer surface of the first inner sealing mandrel 3020 ranges from about 0.005 to 0.01 inches in order to optimally provide minimal  
30 radial clearance. The radial clearance between the outer cylindrical surface of the first upper sealing head 3030 and the inner surface of the casing 3075 may range, for example, from about 0.025 to 0.375 inches. In a preferred embodiment, the

WO 01/04535

PCT/US00/18635

radial clearance between the outer cylindrical surface of the first upper sealing head 3030 and the inner surface of the casing 3075 ranges from about 0.025 to 0.125 inches in order to optimally provide stabilization for the expansion cone 3070 during the expansion process.

5       The first upper sealing head 3030 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The first upper sealing head 3030 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, or other similar high strength materials. In a preferred  
10       embodiment, the first upper sealing head 3030 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces. The inner surface of the first upper sealing head 3030 preferably includes one or more annular sealing members 3145 for sealing the interface between the first upper sealing head 3030 and the first inner sealing mandrel  
15       3020. The sealing members 3145 may comprise any number of conventional commercially available annular sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 3145 comprise polypak seals available from Parker seals in order to optimally provide sealing for a long axial stroke.

20       In a preferred embodiment, the first upper sealing head 3030 includes a shoulder 3150 for supporting the first upper sealing head 3030, first outer sealing mandrel 3040, second upper sealing head 3050, second outer sealing mandrel 3060, and expansion cone 3070 on the first lower sealing head 3035. The first upper  
25       sealing head 3030 may be coupled to the first outer sealing mandrel 3040 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, or a standard threaded connection. In a preferred  
30       embodiment, the first upper sealing head 3030 is removably coupled to the first outer sealing mandrel 3040 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the first upper sealing head 3030 and the first outer sealing mandrel 3040 includes one or more sealing members 3155 for fluidically sealing the interface between the first upper sealing head 3030

WO 01/04535

PCT/US00/18635

and the first outer sealing mandrel 3040. The sealing members 3155 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals, or metal spring energized seals. In a preferred embodiment, the sealing members 3155 comprise polypak seals available from  
5 Parker Seals in order to optimally provide sealing for a long axial stroke.

The first lower sealing head 3035 is coupled to the first inner sealing mandrel 3020 and the second inner sealing mandrel 3045. The first lower sealing head 3035 is also movably coupled to the inner surface of the first outer sealing mandrel 3040. In this manner, the first upper sealing head 3030, first outer  
10 sealing mandrel 3040, second upper sealing head 3050, second outer sealing mandrel 3060, and expansion cone 3070 reciprocate in the axial direction. The radial clearance between the outer surface of the first lower sealing head 3035 and the inner surface of the first outer sealing mandrel 3040 may range, for example, from about 0.0025 to 0.05 inches. In a preferred embodiment, the radial clearance  
15 between the outer surface of the first lower sealing head 3035 and the inner surface of the outer sealing mandrel 3040 ranges from about 0.005 to 0.01 inches in order to optimally provide minimal radial clearance.

The first lower sealing head 3035 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The first lower sealing  
20 head 3035 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the first lower sealing head 3035 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance,  
25 and low friction surfaces. The outer surface of the first lower sealing head 3035 preferably includes one or more annular sealing members 3160 for sealing the interface between the first lower sealing head 3035 and the first outer sealing mandrel 3040. The sealing members 3160 may comprise any number of conventional commercially available annular sealing members such as, for  
30 example, o-rings, polypak seals, or metal spring energized seals. In a preferred embodiment, the sealing members 3160 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

WO 01/04535

PCT/US00/18635

The first lower sealing head 3035 may be coupled to the first inner sealing mandrel 3020 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded  
5 connection or a standard threaded connection. In a preferred embodiment, the first lower sealing head 3035 is removably coupled to the first inner sealing mandrel 3020 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the first lower sealing head 3035 and the first inner  
10 sealing mandrel 3020 includes one or more sealing members 3165 for fluidically sealing the interface between the first lower sealing head 3035 and the first inner sealing mandrel 3020. The sealing members 3165 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals, or metal spring energized seals. In a preferred embodiment, the  
15 sealing members 3165 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke length.

The first lower sealing head 3035 may be coupled to the second inner sealing mandrel 3045 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded  
20 connection or a standard threaded connection. In a preferred embodiment, the first lower sealing head 3035 is removably coupled to the second inner sealing mandrel 3045 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the first lower sealing head 3035 and the second inner sealing mandrel 3045 includes one or more sealing members 3170 for  
25 fluidically sealing the interface between the first lower sealing head 3035 and the second inner sealing mandrel 3045. The sealing members 3170 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 3170 comprise polypak seals available from  
30 Parker Seals in order to optimally provide sealing for a long axial stroke.

The first outer sealing mandrel 3040 is coupled to the first upper sealing head 3030 and the second upper sealing head 3050. The first outer sealing

WO 01/04535

PCT/US00/18635

mandrel 3040 is also movably coupled to the inner surface of the casing 3075 and the outer surface of the first lower sealing head 3035. In this manner, the first upper sealing head 3030, first outer sealing mandrel 3040, second upper sealing head 3050, second outer sealing mandrel 3060, and the expansion cone 3070 reciprocate in the axial direction. The radial clearance between the outer surface of the first outer sealing mandrel 3040 and the inner surface of the casing 3075 may range, for example, from about 0.025 to 0.375 inches. In a preferred embodiment, the radial clearance between the outer surface of the first outer sealing mandrel 3040 and the inner surface of the casing 3075 ranges from about 0.025 to 0.125 inches in order to optimally provide stabilization for the expansion cone 3070 during the expansion process. The radial clearance between the inner surface of the first outer sealing mandrel 3040 and the outer surface of the first lower sealing head 3035 may range, for example, from about 0.005 to 0.125 inches. In a preferred embodiment, the radial clearance between the inner surface of the first outer sealing mandrel 3040 and the outer surface of the first lower sealing head 3035 ranges from about 0.005 to 0.01 inches in order to optimally provide minimal radial clearance.

The first outer sealing mandrel 3040 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The first outer sealing mandrel 3040 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the first outer sealing mandrel 3040 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

The first outer sealing mandrel 3040 may be coupled to the first upper sealing head 3030 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection or a standard threaded connection. In a preferred embodiment, the first outer sealing mandrel 3040 is removably coupled to the first upper sealing head 3030 by a standard threaded connection. In a preferred embodiment, the

WO 01/04535

PCT/US00/18635

mechanical coupling between the first outer sealing mandrel 3040 and the first upper sealing head 3030 includes one or more sealing members 3180 for sealing the interface between the first outer sealing mandrel 3040 and the first upper sealing head 3030. The sealing members 3180 may comprise any number of  
5 conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 3180 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

The first outer sealing mandrel 3040 may be coupled to the second upper  
10 sealing head 3050 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection, or a standard threaded connection. In a preferred embodiment, the first outer sealing mandrel 3040 is removably coupled to the second upper sealing  
15 head 3050 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the first outer sealing mandrel 3040 and the second upper sealing head 3050 includes one or more sealing members 3185 for sealing the interface between the first outer sealing mandrel 3040 and the second upper sealing head 3050. The sealing members 3185 may comprise any number of  
20 conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 3185 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

The second inner sealing mandrel 3045 is coupled to the first lower sealing  
25 head 3035 and the second lower sealing head 3055. The second inner sealing mandrel 3045 preferably comprises a substantially hollow tubular member or members. The second inner sealing mandrel 3045 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other  
30 similar high strength materials. In a preferred embodiment, the second inner sealing mandrel 3045 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

The second inner sealing mandrel 3045 may be coupled to the first lower sealing head 3035 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection or a standard threaded connection. In a preferred embodiment, the second inner sealing mandrel 3045 is removably coupled to the first lower sealing head 3035 by a standard threaded connection. The second inner sealing mandrel 3045 may be coupled to the second lower sealing head 3055 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type connection, or a standard threaded connection. In a preferred embodiment, the second inner sealing mandrel 3045 is removably coupled to the second lower sealing head 3055 by a standard threaded connection.

The second inner sealing mandrel 3045 preferably includes a fluid passage 3100 that is adapted to convey fluidic materials from the fluid passage 3095 into the fluid passage 3105. In a preferred embodiment, the fluid passage 3100 is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The second inner sealing mandrel 3045 further preferably includes fluid passages 3120 that are adapted to convey fluidic materials from the fluid passage 3100 into the second pressure chamber 3190 defined by the second upper sealing head 3050, the second lower sealing head 3055, the second inner sealing mandrel 3045, and the second outer sealing mandrel 3060. During operation of the apparatus 3000, pressurization of the second pressure chamber 3190 causes the first upper sealing head 3030, the first outer sealing mandrel 3040, the second upper sealing head 3050, the second outer sealing mandrel 3060, and the expansion cone 3070 to move in an axial direction.

The second upper sealing head 3050 is coupled to the first outer sealing mandrel 3040 and the second outer sealing mandrel 3060. The second upper sealing head 3050 is also movably coupled to the outer surface of the second inner sealing mandrel 3045 and the inner surface of the casing 3075. In this manner, the



WO 01/04535

PCT/US00/18635

second upper sealing head 3050 reciprocates in the axial direction. The radial clearance between the inner cylindrical surface of the second upper sealing head 3050 and the outer surface of the second inner sealing mandrel 3045 may range, for example, from about 0.0025 to 0.05 inches. In a preferred embodiment, the radial clearance between the inner cylindrical surface of the second upper sealing head 3050 and the outer surface of the second inner sealing mandrel 3045 ranges from about 0.005 to 0.01 inches in order to optimally provide minimal radial clearance. The radial clearance between the outer cylindrical surface of the second upper sealing head 3050 and the inner surface of the casing 3075 may range, for example, from about 0.025 to 0.375 inches. In a preferred embodiment, the radial clearance between the outer cylindrical surface of the second upper sealing head 3050 and the inner surface of the casing 3075 ranges from about 0.025 to 0.125 inches in order to optimally provide stabilization for the expansion cone 3070 during the expansion process.

The second upper sealing head 3050 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The second upper sealing head 3050 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the second upper sealing head 3050 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces. The inner surface of the second upper sealing head 3050 preferably includes one or more annular sealing members 3195 for sealing the interface between the second upper sealing head 3050 and the second inner sealing mandrel 3045. The sealing members 3195 may comprise any number of conventional commercially available annular sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 3195 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

In a preferred embodiment, the second upper sealing head 3050 includes a shoulder 3200 for supporting the first upper sealing head 3030, first outer sealing

WO 01/04535

PCT/US00/18635

mandrel 3040, second upper sealing head 3050, second outer sealing mandrel 3060, and expansion cone 3070 on the second lower sealing head 3055.

The second upper sealing head 3050 may be coupled to the first outer sealing mandrel 3040 using any number of conventional commercially available  
5 mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection, or a standard threaded connection. In a preferred embodiment, the second upper sealing head 3050 is removably coupled to the first outer sealing mandrel 3040 by a standard threaded connection. In a preferred embodiment, the  
10 mechanical coupling between the second upper sealing head 3050 and the first outer sealing mandrel 3040 includes one or more sealing members 3185 for fluidically sealing the interface between the second upper sealing head 3050 and the first outer sealing mandrel 3040. The second upper sealing head 3050 may be coupled to the second outer sealing mandrel 3060 using any number of  
15 conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type threaded connection, or a standard threaded connection. In a preferred embodiment, the second upper sealing head 3050 is removably coupled to the second outer sealing mandrel 3060 by a standard  
20 threaded connection. In a preferred embodiment, the mechanical coupling between the second upper sealing head 3050 and the second outer sealing mandrel 3060 includes one or more sealing members 3205 for fluidically sealing the interface between the second upper sealing head 3050 and the second outer sealing mandrel 3060.

25 The second lower sealing head 3055 is coupled to the second inner sealing mandrel 3045 and the load mandrel 3065. The second lower sealing head 3055 is also movably coupled to the inner surface of the second outer sealing mandrel 3060. In this manner, the first upper sealing head 3030, first outer sealing mandrel 3040, second upper sealing mandrel 3050, second outer sealing mandrel  
30 3060, and expansion cone 3070 reciprocate in the axial direction. The radial clearance between the outer surface of the second lower sealing head 3055 and the inner surface of the second outer sealing mandrel 3060 may range, for example,

WO 01/04535

PCT/US00/18635

from about 0.0025 to 0.05 inches. In a preferred embodiment, the radial clearance between the outer surface of the second lower sealing head 3055 and the inner surface of the second outer sealing mandrel 3060 ranges from about 0.005 to 0.01 inches in order to optimally provide minimal radial clearance.

5        The second lower sealing head 3055 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The second lower sealing head 3055 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel, or other similar high strength  
10 materials. In a preferred embodiment, the second lower sealing head 3055 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces. The outer surface of the second lower sealing head 3055 preferably includes one or more annular sealing members 3210 for sealing the interface between the second lower sealing head 3055 and the  
15 second outer sealing mandrel 3060. The sealing members 3210 may comprise any number of conventional commercially available annular sealing members such as, for example, o-rings, polypak seals, or metal spring energized seals. In a preferred embodiment, the sealing members 3210 comprise polypak seals available from Parker Seals in order to optimally provide sealing for long axial strokes.

20        The second lower sealing head 3055 may be coupled to the second inner sealing mandrel 3045 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, or a standard threaded connection. In a preferred embodiment, the second lower sealing head 3055 is  
25 removably coupled to the second inner sealing mandrel 3045 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the lower sealing head 3055 and the second inner sealing mandrel 3045 includes one or more sealing members 3215 for fluidically sealing the interface between the second lower sealing head 3055 and the second inner sealing mandrel  
30 3045. The sealing members 3215 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing

WO 01/04535

PCT/US00/18635

members 3215 comprise polypak seals available from Parker Seals in order to optimally provide sealing for long axial strokes.

The second lower sealing head 3055 may be coupled to the load mandrel 3065 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, or a standard threaded connection. In a preferred embodiment, the second lower sealing head 3055 is removably coupled to the load mandrel 3065 by a standard threaded connection. In a preferred embodiment, the mechanical coupling between the second lower sealing head 3055 and the load mandrel 3065 includes one or more sealing members 3220 for fluidically sealing the interface between the second lower sealing head 3055 and the load mandrel 3065. The sealing members 3220 may comprise any number of conventional commercially available sealing members such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the sealing members 3220 comprise polypak seals available from Parker Seals in order to optimally provide sealing for a long axial stroke.

In a preferred embodiment, the second lower sealing head 3055 includes a throat passage 3225 fluidically coupled between the fluid passages 3100 and 3105. The throat passage 3225 is preferably of reduced size and is adapted to receive and engage with a plug 3230, or other similar device. In this manner, the fluid passage 3100 is fluidically isolated from the fluid passage 3105. In this manner, the pressure chambers 3175 and 3190 are pressurized. Furthermore, the placement of the plug 3230 in the throat passage 3225 also pressurizes the pressure chambers 3130 of the hydraulic slips 3025.

The second outer sealing mandrel 3060 is coupled to the second upper sealing head 3050 and the expansion cone 3070. The second outer sealing mandrel 3060 is also movably coupled to the inner surface of the casing 3075 and the outer surface of the second lower sealing head 3055. In this manner, the first upper sealing head 3030, first outer sealing mandrel 3040, second upper sealing head 3050, second outer sealing mandrel 3060, and the expansion cone 3070 reciprocate in the axial direction. The radial clearance between the outer surface of the second outer sealing mandrel 3060 and the inner surface of the casing 3075 may

WO 01/04535

PCT/US00/18635

range, for example, from about 0.025 to 0.375 inches. In a preferred embodiment, the radial clearance between the outer surface of the second outer sealing mandrel 3060 and the inner surface of the casing 3075 ranges from about 0.025 to 0.125 inches in order to optimally provide stabilization for the expansion cone 3070

5 during the expansion process. The radial clearance between the inner surface of the second outer sealing mandrel 3060 and the outer surface of the second lower sealing head 3055 may range, for example, from about 0.0025 to 0.05 inches. In a preferred embodiment, the radial clearance between the inner surface of the second outer sealing mandrel 3060 and the outer surface of the second lower

10 sealing head 3055 ranges from about 0.005 to 0.01 inches in order to optimally provide minimal radial clearance.

The second outer sealing mandrel 3060 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The second outer sealing mandrel 3060 may be fabricated from any number of conventional

15 commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the second outer sealing mandrel 3060 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

20 The second outer sealing mandrel 3060 may be coupled to the second upper sealing head 3050 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, or a standard threaded connection. In a preferred embodiment, the outer sealing mandrel 3060 is

25 removably coupled to the second upper sealing head 3050 by a standard threaded connection. The second outer sealing mandrel 3060 may be coupled to the expansion cone 3070 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, or a standard threaded

30 connection. In a preferred embodiment, the second outer sealing mandrel 3060 is removably coupled to the expansion cone 3070 by a standard threaded connection.

WO 01/04535

PCT/US00/18635

The first upper sealing head 3030, the first lower sealing head 3035, the first inner sealing mandrel 3020, and the first outer sealing mandrel 3040 together define the first pressure chamber 3175. The second upper sealing head 3050, the second lower sealing head 3055, the second inner sealing mandrel 3045, and the second outer sealing mandrel 3060 together define the second pressure chamber 3190. The first and second pressure chambers, 3175 and 3190, are fluidically coupled to the passages, 3095 and 3100, via one or more passages, 3115 and 3120. During operation of the apparatus 3000, the plug 3230 engages with the throat passage 3225 to fluidically isolate the fluid passage 3100 from the fluid passage 3105.

10 The pressure chambers, 3175 and 3190, are then pressurized which in turn causes the first upper sealing head 3030, the first outer sealing mandrel 3040, the second upper sealing head 3050, the second outer sealing mandrel 3060, and expansion cone 3070 to reciprocate in the axial direction. The axial motion of the expansion cone 3070 in turn expands the casing 3075 in the radial direction. The use of a plurality of pressure chambers, 3175 and 3190, effectively multiplies the available driving force for the expansion cone 3070.

The load mandrel 3065 is coupled to the second lower sealing head 3055. The load mandrel 3065 preferably comprises an annular member having substantially cylindrical inner and outer surfaces. The load mandrel 3065 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, stainless steel or other similar high strength materials. In a preferred embodiment, the load mandrel 3065 is fabricated from stainless steel in order to optimally provide high strength, corrosion resistance, and low friction surfaces.

25 The load mandrel 3065 may be coupled to the lower sealing head 3055 using any number of conventional commercially available mechanical couplings such as, for example, epoxy, cement, water, drilling mud, or lubricants. In a preferred embodiment, the load mandrel 3065 is removably coupled to the lower sealing head 3055 by a standard threaded connection.

30 The load mandrel 3065 preferably includes a fluid passage 3105 that is adapted to convey fluidic materials from the fluid passage 3100 to the region outside of the apparatus 3000. In a preferred embodiment, the fluid passage 3105

WO 01/04535

PCT/US00/18635

is adapted to convey fluidic materials such as, for example, cement, epoxy, water, drilling mud or lubricants at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The expansion cone 3070 is coupled to the second outer sealing mandrel  
5 3060. The expansion cone 3070 is also movably coupled to the inner surface of the casing 3075. In this manner, the first upper sealing head 3030, first outer sealing mandrel 3040, second upper sealing head 3050, second outer sealing mandrel 3060, and the expansion cone 3070 reciprocate in the axial direction. The reciprocation of the expansion cone 3070 causes the casing 3075 to expand in the radial  
10 direction.

The expansion cone 3070 preferably comprises an annular member having substantially cylindrical inner and conical outer surfaces. The outside radius of the outside conical surface may range, for example, from about 2 to 34 inches. In a preferred embodiment, the outside radius of the outside conical surface ranges  
15 from about 3 to 28 inches in order to optimally provide an expansion cone 3070 for expanding typical casings. The axial length of the expansion cone 3070 may range, for example, from about 2 to 8 times the maximum outer diameter of the expansion cone 3070. In a preferred embodiment, the axial length of the expansion cone 3070 ranges from about 3 to 5 times the maximum outer diameter of the  
20 expansion cone 3070 in order to optimally provide stabilization and centralization of the expansion cone 3070 during the expansion process. In a particularly preferred embodiment, the maximum outside diameter of the expansion cone 3070 is between about 95 to 99 % of the inside diameter of the existing wellbore that the casing 3075 will be joined with. In a preferred embodiment, the angle of attack of  
25 the expansion cone 3070 ranges from about 5 to 30 degrees in order to optimally balance the frictional forces with the radial expansion forces.

The expansion cone 3070 may be fabricated from any number of conventional commercially available materials such as, for example, machine tool steel, nitride steel, titanium, tungsten carbide, ceramics, or other similar high  
30 strength materials. In a preferred embodiment, the expansion cone 3070 is fabricated from D2 machine tool steel in order to optimally provide high strength and resistance to wear and galling. In a particularly preferred embodiment, the

WO 01/04535

PCT/US00/18635

outside surface of the expansion cone 3070 has a surface hardness ranging from about 58 to 62 Rockwell C in order to optimally provide high strength and resistance to wear and galling.

The expansion cone 3070 may be coupled to the second outside sealing  
5 mandrel 3060 using any number of conventional commercially available mechanical couplings such as, for example, drillpipe connection, oilfield country tubular goods specialty type threaded connection, ratchet-latch type connection or a standard threaded connection. In a preferred embodiment, the expansion cone 3070 is coupled to the second outside sealing mandrel 3060 using a standard  
10 threaded connection in order to optimally provide high strength and easy disassembly.

The casing 3075 is removably coupled to the slips 3025 and the expansion cone 3070. The casing 3075 preferably comprises a tubular member. The casing 3075 may be fabricated from any number of conventional commercially available  
15 materials such as, for example, slotted tubulars, oilfield country tubular goods, carbon steel, low alloy steel, stainless steel, or other similar high strength materials. In a preferred embodiment, the casing 3075 is fabricated from oilfield country tubular goods available from various foreign and domestic steel mills in order to optimally provide high strength.

20 In a preferred embodiment, the upper end 3235 of the casing 3075 includes a thin wall section 3240 and an outer annular sealing member 3245. In a preferred embodiment, the wall thickness of the thin wall section 3240 is about 50 to 100 % of the regular wall thickness of the casing 3075. In this manner, the upper end 3235 of the casing 3075 may be easily radially expanded and deformed into  
25 intimate contact with the lower end of an existing section of wellbore casing. In a preferred embodiment, the lower end of the existing section of casing also includes a thin wall section. In this manner, the radial expansion of the thin walled section 3240 of casing 3075 into the thin walled section of the existing wellbore casing results in a wellbore casing having a substantially constant inside  
30 diameter.

The annular sealing member 3245 may be fabricated from any number of conventional commercially available sealing materials such as, for example, epoxy,



WO 01/04535

PCT/US00/18635

rubber, metal or plastic. In a preferred embodiment, the annular sealing member 3245 is fabricated from StrataLock epoxy in order to optimally provide compressibility and wear resistance. The outside diameter of the annular sealing member 3245 preferably ranges from about 70 to 95 % of the inside diameter of the lower section of the wellbore casing that the casing 3075 is joined to. In this manner, after radial expansion, the annular sealing member 3245 optimally provides a fluidic seal and also preferably optimally provides sufficient frictional force with the inside surface of the existing section of wellbore casing during the radial expansion of the casing 3075 to support the casing 3075.

10 In a preferred embodiment, the lower end 3250 of the casing 3075 includes a thin wall section 3255 and an outer annular sealing member 3260. In a preferred embodiment, the wall thickness of the thin wall section 3255 is about 50 to 100 % of the regular wall thickness of the casing 3075. In this manner, the lower end 3250 of the casing 3075 may be easily expanded and deformed. Furthermore, in this manner, an other section of casing may be easily joined with the lower end 15 3250 of the casing 3075 using a radial expansion process. In a preferred embodiment, the upper end of the other section of casing also includes a thin wall section. In this manner, the radial expansion of the thin walled section of the upper end of the other casing into the thin walled section 3255 of the lower end 20 3250 of the casing 3075 results in a wellbore casing having a substantially constant inside diameter.

The upper annular sealing member 3245 may be fabricated from any number of conventional commercially available sealing materials such as, for example, epoxy, rubber, metal or plastic. In a preferred embodiment, the upper 25 annular sealing member 3245 is fabricated from Stratalock epoxy in order to optimally provide compressibility and resistance to wear. The outside diameter of the upper annular sealing member 3245 preferably ranges from about 70 to 95 % of the inside diameter of the lower section of the existing wellbore casing that the casing 3075 is joined to. In this manner, after radial expansion, the upper annular 30 sealing member 3245 preferably provides a fluidic seal and also preferably provides sufficient frictional force with the inside wall of the wellbore during the radial expansion of the casing 3075 to support the casing 3075.

WO 01/04535

PCT/US00/18635

The lower annular sealing member 3260 may be fabricated from any number of conventional commercially available sealing materials such as, for example, epoxy, rubber, metal or plastic. In a preferred embodiment, the lower annular sealing member 3260 is fabricated from StrataLock epoxy in order to optimally provide compressibility and resistance to wear. The outside diameter of the lower annular sealing member 3260 preferably ranges from about 70 to 95 % of the inside diameter of the lower section of the existing wellbore casing that the casing 3075 is joined to. In this manner, the lower annular sealing member 3260 preferably provides a fluidic seal and also preferably provides sufficient frictional force with the inside wall of the wellbore during the radial expansion of the casing 3075 to support the casing 3075.

During operation, the apparatus 3000 is preferably positioned in a wellbore with the upper end 3235 of the casing 3075 positioned in an overlapping relationship with the lower end of an existing wellbore casing. In a particularly preferred embodiment, the thin wall section 3240 of the casing 3075 is positioned in opposing overlapping relation with the thin wall section and outer annular sealing member of the lower end of the existing section of wellbore casing. In this manner, the radial expansion of the casing 3075 will compress the thin wall sections and annular compressible members of the upper end 3235 of the casing 3075 and the lower end of the existing wellbore casing into intimate contact. During the positioning of the apparatus 3000 in the wellbore, the casing 3000 is preferably supported by the expansion cone 3070.

After positioning the apparatus 3000, a first fluidic material is then pumped into the fluid passage 3080. The first fluidic material may comprise any number of conventional commercially available materials such as, for example, drilling mud, water, epoxy, cement, slag mix or lubricants. In a preferred embodiment, the first fluidic material comprises a hardenable fluidic sealing material such as, for example, cement, epoxy, or slag mix in order to optimally provide a hardenable outer annular body around the expanded casing 3075.

The first fluidic material may be pumped into the fluid passage 3080 at operating pressures and flow rates ranging, for example, from about 0 to 4,500 psi and 0 to 4,500 gallons/minute. In a preferred embodiment, the first fluidic

WO 01/04535

PCT/US00/18635

material is pumped into the fluid passage 3080 at operating pressures and flow rates ranging from about 0 to 3,500 psi and 0 to 1,200 gallons/minute in order to optimally provide operating efficiency.

5 The first fluidic material pumped into the fluid passage 3080 passes through the fluid passages 3085, 3090, 3095, 3100, and 3105 and then outside of the apparatus 3000. The first fluidic material then preferably fills the annular region between the outside of the apparatus 3000 and the interior walls of the wellbore.

The plug 3230 is then introduced into the fluid passage 3080. The plug 3230 lodges in the throat passage 3225 and fluidically isolates and blocks off the fluid  
10 passage 3100. In a preferred embodiment, a couple of volumes of a non-hardenable fluidic material are then pumped into the fluid passage 3080 in order to remove any hardenable fluidic material contained within and to ensure that none of the fluid passages are blocked.

A second fluidic material is then pumped into the fluid passage 3080. The  
15 second fluidic material may comprise any number of conventional commercially available materials such as, for example, water, drilling gases, drilling mud or lubricant. In a preferred embodiment, the second fluidic material comprises a non-hardenable fluidic material such as, for example, water, drilling mud, drilling gases, or lubricant in order to optimally provide pressurization of the pressure  
20 chambers 3175 and 3190.

The second fluidic material may be pumped into the fluid passage 3080 at operating pressures and flow rates ranging, for example, from about 0 to 4,500 psi and 0 to 4,500 gallons/minute. In a preferred embodiment, the second fluidic material is pumped into the fluid passage 3080 at operating pressures and flow  
25 rates ranging from about 0 to 3,500 psi and 0 to 1,200 gallons/minute in order to optimally provide operational efficiency.

The second fluidic material pumped into the fluid passage 3080 passes through the fluid passages 3085, 3090, 3095, 3100 and into the pressure chambers 3130 of the slips 3025, and into the pressure chambers 3175 and 3190. Continued  
30 pumping of the second fluidic material pressurizes the pressure chambers 3130, 3175, and 3190.

WO 01/04535

PCT/US00/18635

The pressurization of the pressure chambers 3130 causes the hydraulic slip members 3140 to expand in the radial direction and grip the interior surface of the casing 3075. The casing 3075 is then preferably maintained in a substantially stationary position.

- 5        The pressurization of the pressure chambers 3175 and 3190 cause the first upper sealing head 3030, first outer sealing mandrel 3040, second upper sealing head 3050, second outer sealing mandrel 3060, and expansion cone 3070 to move in an axial direction relative to the casing 3075. In this manner, the expansion cone 3070 will cause the casing 3075 to expand in the radial direction, beginning  
10    with the lower end 3250 of the casing 3075.

- During the radial expansion process, the casing 3075 is prevented from moving in an upward direction by the slips 3025. A length of the casing 3075 is then expanded in the radial direction through the pressurization of the pressure chambers 3175 and 3190. The length of the casing 3075 that is expanded during  
15    the expansion process will be proportional to the stroke length of the first upper sealing head 3030, first outer sealing mandrel 3040, second upper sealing head 3050, and expansion cone 3070.

- Upon the completion of a stroke, the operating pressure of the second fluidic material is reduced and the first upper sealing head 3030, first outer sealing  
20    mandrel 3040, second upper sealing head 3050, second outer sealing mandrel 3060, and expansion cone 3070 drop to their rest positions with the casing 3075 supported by the expansion cone 3070. The reduction in the operating pressure of the second fluidic material also causes the spring bias 3135 of the slips 3025 to pull the slip members 3140 away from the inside walls of the casing 3075.

- 25        The position of the drillpipe 3075 is preferably adjusted throughout the radial expansion process in order to maintain the overlapping relationship between the thin walled sections of the lower end of the existing wellbore casing and the upper end of the casing 3235. In a preferred embodiment, the stroking of the expansion cone 3070 is then repeated, as necessary, until the thin walled section  
30    3240 of the upper end 3235 of the casing 3075 is expanded into the thin walled section of the lower end of the existing wellbore casing. In this manner, a wellbore casing is formed including two adjacent sections of casing having a substantially

WO 01/04535

PCT/US00/18635

constant inside diameter. This process may then be repeated for the entirety of the wellbore to provide a wellbore casing thousands of feet in length having a substantially constant inside diameter.

- In a preferred embodiment, during the final stroke of the expansion cone
- 5 3070, the slips 3025 are positioned as close as possible to the thin walled section 3240 of the upper end 3235 of the casing 3075 in order minimize slippage between the casing 3075 and the existing wellbore casing at the end of the radial expansion process. Alternatively, or in addition, the outside diameter of the upper annular sealing member 3245 is selected to ensure sufficient interference fit with the inside
- 10 diameter of the lower end of the existing casing to prevent axial displacement of the casing 3075 during the final stroke. Alternatively, or in addition, the outside diameter of the lower annular sealing member 3260 is selected to provide an interference fit with the inside walls of the wellbore at an earlier point in the radial expansion process so as to prevent further axial displacement of the casing 3075.
- 15 In this final alternative, the interference fit is preferably selected to permit expansion of the casing 3075 by pulling the expansion cone 3070 out of the wellbore, without having to pressurize the pressure chambers 3175 and 3190.

- During the radial expansion process, the pressurized areas of the apparatus 3000 are preferably limited to the fluid passages 3080, 3085, 3090, 3095, 3100,
- 20 3110, 3115, 3120, the pressure chambers 3130 within the slips 3025, and the pressure chambers 3175 and 3190. No fluid pressure acts directly on the casing 3075. This permits the use of operating pressures higher than the casing 3075 could normally withstand.

- Once the casing 3075 has been completely expanded off of the expansion
- 25 cone 3070, the remaining portions of the apparatus 3000 are removed from the wellbore. In a preferred embodiment, the contact pressure between the deformed thin wall sections and compressible annular members of the lower end of the existing casing and the upper end 3235 of the casing 3075 ranges from about 400 to 10,000 psi in order to optimally support the casing 3075 using the existing
- 30 wellbore casing.

In this manner, the casing 3075 is radially expanded into contact with an existing section of casing by pressurizing the interior fluid passages 3080, 3085,

WO 01/04535

PCT/US00/18635

3090, 3095, 3100, 3110, 3115, and 3120, the pressure chambers 3130 of the slips 3025 and the pressure chambers 3175 and 3190 of the apparatus 3000.

In a preferred embodiment, as required, the annular body of hardenable fluidic material is then allowed to cure to form a rigid outer annular body about  
5 the expanded casing 3075. In the case where the casing 3075 is slotted, the cured fluidic material preferably permeates and envelops the expanded casing 3075. The resulting new section of wellbore casing includes the expanded casing 3075 and the rigid outer annular body. The overlapping joint between the pre-existing wellbore casing and the expanded casing 3075 includes the deformed thin wall sections and  
10 the compressible outer annular bodies. The inner diameter of the resulting combined wellbore casings is substantially constant. In this manner, a mono-diameter wellbore casing is formed. This process of expanding overlapping tubular members having thin wall end portions with compressible annular bodies into contact can be repeated for the entire length of a wellbore. In this manner, a  
15 mono-diameter wellbore casing can be provided for thousands of feet in a subterranean formation.

In a preferred embodiment, as the expansion cone 3070 nears the upper end 3235 of the casing 3075, the operating flow rate of the second fluidic material is reduced in order to minimize shock to the apparatus 3000. In an alternative  
20 embodiment, the apparatus 3000 includes a shock absorber for absorbing the shock created by the completion of the radial expansion of the casing 3075.

In a preferred embodiment, the reduced operating pressure of the second fluidic material ranges from about 100 to 1,000 psi as the expansion cone 3070 nears the end of the casing 3075 in order to optimally provide reduced axial  
25 movement and velocity of the expansion cone 3070. In a preferred embodiment, the operating pressure of the second fluidic material is reduced during the return stroke of the apparatus 3000 to the range of about 0 to 500 psi in order minimize the resistance to the movement of the expansion cone 3070 during the return stroke. In a preferred embodiment, the stroke length of the apparatus 3000 ranges  
30 from about 10 to 45 feet in order to optimally provide equipment that can be easily handled by typical oil well rigging equipment and also minimize the frequency at which the apparatus 3000 must be re-stroked.

WO 01/04535

PCT/US00/18635

In an alternative embodiment, at least a portion of one or both of the upper sealing heads, 3030 and 3050, includes an expansion cone for radially expanding the casing 3075 during operation of the apparatus 3000 in order to increase the surface area of the casing 3075 acted upon during the radial expansion process.

5 In this manner, the operating pressures can be reduced.

Alternatively, the apparatus 3000 may be used to join a first section of pipeline to an existing section of pipeline. Alternatively, the apparatus 3000 may be used to directly line the interior of a wellbore with a casing, without the use of an outer annular layer of a hardenable material. Alternatively, the apparatus 3000  
10 may be used to expand a tubular support member in a hole.

Referring now to Figure 21, an apparatus 3330 for isolating subterranean zones will be described. A wellbore 3305 including a casing 3310 are positioned in a subterranean formation 3315. The subterranean formation 3315 includes a number of productive and non-productive zones, including a water zone 3320 and  
15 a targeted oil sand zone 3325. During exploration of the subterranean formation 3315, the wellbore 3305 may be extended in a well known manner to traverse the various productive and non-productive zones, including the water zone 3320 and the targeted oil sand zone 3325.

In a preferred embodiment, in order to fluidically isolate the water zone 3320  
20 from the targeted oil sand zone 3325, an apparatus 3330 is provided that includes one or more sections of solid casing 3335, one or more external seals 3340, one or more sections of slotted casing 3345, one or more intermediate sections of solid casing 3350, and a solid shoe 3355.

The solid casing 3335 may provide a fluid conduit that transmits fluids and  
25 other materials from one end of the solid casing 3335 to the other end of the solid casing 3335. The solid casing 3335 may comprise any number of conventional commercially available sections of solid tubular casing such as, for example, oilfield tubulars fabricated from chromium steel or fiberglass. In a preferred embodiment, the solid casing 3335 comprises oilfield tubulars available from various foreign and  
30 domestic steel mills.

The solid casing 3335 is preferably coupled to the casing 3310. The solid casing 3335 may be coupled to the casing 3310 using any number of conventional

WO 01/04535

PCT/US00/18635

commercially available processes such as, for example, welding, slotted and expandable connectors, or expandable solid connectors. In a preferred embodiment, the solid casing 3335 is coupled to the casing 3310 by using expandable solid connectors. The solid casing 3335 may comprise a plurality of  
5 such solid casings 3335.

The solid casing 3335 is preferably coupled to one more of the slotted casings 3345. The solid casing 3335 may be coupled to the slotted casing 3345 using any number of conventional commercially available processes such as, for example, welding, or slotted and expandable connectors. In a preferred  
10 embodiment, the solid casing 3335 is coupled to the slotted casing 3345 by expandable solid connectors.

In a preferred embodiment, the casing 3335 includes one more valve members 3360 for controlling the flow of fluids and other materials within the interior region of the casing 3335. In an alternative embodiment, during the  
15 production mode of operation, an internal tubular string with various arrangements of packers, perforated tubing, sliding sleeves, and valves may be employed within the apparatus to provide various options for commingling and isolating subterranean zones from each other while providing a fluid path to the surface.

In a particularly preferred embodiment, the casing 3335 is placed into the wellbore 3305 by expanding the casing 3335 in the radial direction into intimate contact with the interior walls of the wellbore 3305. The casing 3335 may be expanded in the radial direction using any number of conventional commercially available methods. In a preferred embodiment, the casing 3335 is expanded in the  
20 radial direction using one or more of the processes and apparatus described within the present disclosure.

The seals 3340 prevent the passage of fluids and other materials within the annular region 3365 between the solid casings 3335 and 3350 and the wellbore 3305. The seals 3340 may comprise any number of conventional commercially  
30 available sealing materials suitable for sealing a casing in a wellbore such as, for example, lead, rubber or epoxy. In a preferred embodiment, the seals 3340 comprise Stratalok epoxy material available from Halliburton Energy Services.



WO 01/04535

PCT/US00/18635

The slotted casing 3345 permits fluids and other materials to pass into and out of the interior of the slotted casing 3345 from and to the annular region 3365. In this manner, oil and gas may be produced from a producing subterranean zone within a subterranean formation. The slotted casing 3345 may comprise any  
5 number of conventional commercially available sections of slotted tubular casing. In a preferred embodiment, the slotted casing 3345 comprises expandable slotted tubular casing available from Petrolite in Aberdeen, Scotland. In a particularly preferred embodiment, the slotted casing 145 comprises expandable slotted sandscreen tubular casing available from Petrolite in Aberdeen, Scotland.

10 The slotted casing 3345 is preferably coupled to one or more solid casing 3335. The slotted casing 3345 may be coupled to the solid casing 3335 using any number of conventional commercially available processes such as, for example, welding, or slotted or solid expandable connectors. In a preferred embodiment, the slotted casing 3345 is coupled to the solid casing 3335 by expandable solid  
15 connectors.

The slotted casing 3345 is preferably coupled to one or more intermediate solid casings 3350. The slotted casing 3345 may be coupled to the intermediate solid casing 3350 using any number of conventional commercially available processes such as, for example, welding or expandable solid or slotted connectors.  
20 In a preferred embodiment, the slotted casing 3345 is coupled to the intermediate solid casing 3350 by expandable solid connectors.

The last section of slotted casing 3345 is preferably coupled to the shoe 3355. The last slotted casing 3345 may be coupled to the shoe 3355 using any number of conventional commercially available processes such as, for example,  
25 welding or expandable solid or slotted connectors. In a preferred embodiment, the last slotted casing 3345 is coupled to the shoe 3355 by an expandable solid connector.

In an alternative embodiment, the shoe 3355 is coupled directly to the last one of the intermediate solid casings 3350.

30 In a preferred embodiment, the slotted casings 3345 are positioned within the wellbore 3305 by expanding the slotted casings 3345 in a radial direction into intimate contact with the interior walls of the wellbore 3305. The slotted casings

WO 01/04535

PCT/US00/18635

3345 may be expanded in a radial direction using any number of conventional commercially available processes. In a preferred embodiment, the slotted casings 3345 are expanded in the radial direction using one or more of the processes and apparatus disclosed in the present disclosure with reference to Figures 14a-20.

5       The intermediate solid casing 3350 permits fluids and other materials to pass between adjacent slotted casings 3345. The intermediate solid casing 3350 may comprise any number of conventional commercially available sections of solid tubular casing such as, for example, oilfield tubulars fabricated from chromium steel or fiberglass. In a preferred embodiment, the intermediate solid casing 3350  
10 comprises oilfield tubulars available from foreign and domestic steel mills.

      The intermediate solid casing 3350 is preferably coupled to one or more sections of the slotted casing 3345. The intermediate solid casing 3350 may be coupled to the slotted casing 3345 using any number of conventional commercially available processes such as, for example, welding, or solid or slotted expandable  
15 connectors. In a preferred embodiment, the intermediate solid casing 3350 is coupled to the slotted casing 3345 by expandable solid connectors. The intermediate solid casing 3350 may comprise a plurality of such intermediate solid casing 3350.

      In a preferred embodiment, each intermediate solid casing 3350 includes  
20 one more valve members 3370 for controlling the flow of fluids and other materials within the interior region of the intermediate casing 3350. In an alternative embodiment, as will be recognized by persons having ordinary skill in the art and the benefit of the present disclosure, during the production mode of operation, an internal tubular string with various arrangements of packers, perforated tubing,  
25 sliding sleeves, and valves may be employed within the apparatus to provide various options for commingling and isolating subterranean zones from each other while providing a fluid path to the surface.

      In a particularly preferred embodiment, the intermediate casing 3350 is placed into the wellbore 3305 by expanding the intermediate casing 3350 in the  
30 radial direction into intimate contact with the interior walls of the wellbore 3305. The intermediate casing 3350 may be expanded in the radial direction using any number of conventional commercially available methods.

WO 01/04535

PCT/US00/18635

In an alternative embodiment, one or more of the intermediate solid casings 3350 may be omitted. In an alternative preferred embodiment, one or more of the slotted casings 3345 are provided with one or more seals 3340.

The shoe 3355 provides a support member for the apparatus 3330. In this manner, various production and exploration tools may be supported by the shoe 3350. The shoe 3350 may comprise any number of conventional commercially available shoes suitable for use in a wellbore such as, for example, cement filled shoe, or an aluminum or composite shoe. In a preferred embodiment, the shoe 3350 comprises an aluminum shoe available from Halliburton. In a preferred embodiment, the shoe 3355 is selected to provide sufficient strength in compression and tension to permit the use of high capacity production and exploration tools.

In a particularly preferred embodiment, the apparatus 3330 includes a plurality of solid casings 3335, a plurality of seals 3340, a plurality of slotted casings 3345, a plurality of intermediate solid casings 3350, and a shoe 3355. More generally, the apparatus 3330 may comprise one or more solid casings 3335, each with one or more valve members 3360, n slotted casings 3345, n-1 intermediate solid casings 3350, each with one or more valve members 3370, and a shoe 3355.

During operation of the apparatus 3330, oil and gas may be controllably produced from the targeted oil sand zone 3325 using the slotted casings 3345. The oil and gas may then be transported to a surface location using the solid casing 3335. The use of intermediate solid casings 3350 with valve members 3370 permits isolated sections of the zone 3325 to be selectively isolated for production. The seals 3340 permit the zone 3325 to be fluidically isolated from the zone 3320. The seals 3340 further permits isolated sections of the zone 3325 to be fluidically isolated from each other. In this manner, the apparatus 3330 permits unwanted and/or non-productive subterranean zones to be fluidically isolated.

In an alternative embodiment, as will be recognized by persons having ordinary skill in the art and also having the benefit of the present disclosure, during the production mode of operation, an internal tubular string with various arrangements of packers, perforated tubing, sliding sleeves, and valves may be employed within the apparatus to provide various options for commingling and

WO 01/04535

PCT/US00/18635

isolating subterranean zones from each other while providing a fluid path to the surface.

Referring to Figures 22a, 22b, 22c and 22d, an embodiment of an apparatus 3500 for forming a wellbore casing while drilling a wellbore will now be described.

- 5 In a preferred embodiment, the apparatus 3500 includes a support member 3505, a mandrel 3510, a mandrel launcher 3515, a shoe 3520, a tubular member 3525, a mud motor 3530, a drill bit 3535, a first fluid passage 3540, a second fluid passage 3545, a pressure chamber 3550, a third fluid passage 3555, a cup seal 3560, a body of lubricant 3565, seals 3570, and a releasable coupling 3600.
- 10 The support member 3505 is coupled to the mandrel 3510. The support member 3505 preferably comprises an annular member having sufficient strength to carry and support the apparatus 3500 within the wellbore 3575. In a preferred embodiment, the support member 3505 further includes one or more conventional centralizers (not illustrated) to help stabilize the apparatus 3500.
- 15 The support member 3505 may comprise one or more sections of conventional commercially available tubular materials such as, for example, oilfield country tubular goods, low alloy steel, stainless steel or carbon steel. In a preferred embodiment, the support member 3505 comprises coiled tubing or drillpipe in order to optimally permit the placement of the apparatus 3500 within
- 20 a non-vertical wellbore.
- In a preferred embodiment, the support member 3505 includes a first fluid passage 3540 for conveying fluidic materials from a surface location to the fluid passage 3545. In a preferred embodiment, the first fluid passage 3540 is adapted to convey fluidic materials such as water, drilling mud, cement, epoxy or slag mix
- 25 at operating pressures and flow rates ranging from about 0 to 10,000 psi and 0 to 3,000 gallons/minute.
- The mandrel 3510 is coupled to and supported by the support member 3505. The mandrel 3510 is also coupled to and supports the mandrel launcher 3515 and tubular member 3525. The mandrel 3510 is preferably adapted to controllably
- 30 expand in a radial direction. The mandrel 3510 may comprise any number of conventional commercially available mandrels modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the mandrel 3510

WO 01/04535

PCT/US00/18635

comprises a hydraulic expansion tool as disclosed in U.S. Patent No. 5,348,095, the contents of which are incorporated herein by reference, modified in accordance with the teachings of the present disclosure.

In a preferred embodiment, the mandrel 3510 includes one or more conical  
5 sections for expanding the tubular member 3525 in the radial direction. In a preferred embodiment, the outer surfaces of the conical sections of the mandrel 3510 have a surface hardness ranging from about 58 to 62 Rockwell C in order to optimally radially expand the tubular member 3525.

In a preferred embodiment, the mandrel 3510 includes a second fluid  
10 passage 3545 fluidically coupled to the first fluid passage 3540 and the pressure chamber 3550 for conveying fluidic materials from the first fluid passage 3540 to the pressure chamber 3550. In a preferred embodiment, the second fluid passage 3545 is adapted to convey fluidic materials such as water, drilling mud, cement, epoxy or slag mix at operating pressures and flow rates ranging from about 0 to  
15 12,000 psi and 0 to 3,500 gallons/minute in order to optimally provide operating pressure for efficient operation.

The mandrel launcher 3515 is coupled to the tubular member 3525, the mandrel 3510, and the shoe 3520. The mandrel launcher 3515 preferably comprises a tapered annular member that mates with at a portion of at least one  
20 of the conical portions of the outer surface of the mandrel 3510. In a preferred embodiment, the wall thickness of the mandrel launcher is less than the wall thickness of the tubular member 3525 in order to facilitate the initiation of the radial expansion process and facilitate the placement of the apparatus in openings having tight clearances. In a preferred embodiment, the wall thickness of the  
25 mandrel launcher 3515 ranges from about 50 to 100 % of the wall thickness of the tubular member 3525 immediately adjacent to the mandrel launcher 3515 in order to optimally facilitate the radial expansion process and facilitate the insertion of the apparatus 3500 into wellbore casings and other areas with tight clearances.

The mandrel launcher 3515 may be fabricated from any number of  
30 conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel or stainless steel. In a preferred embodiment, the mandrel launcher 3515 is fabricated from oilfield

WO 01/04535

PCT/US00/18635

country tubular goods of higher strength by lower wall thickness than the tubular member 3525 in order to optimally provide a smaller container having approximately the same burst strength as the tubular member 3525.

The shoe 3520 is coupled to the mandrel launcher 3515 and the releasable coupling 3600. The shoe 3520 preferably comprises a substantially annular member. In a preferred embodiment, the shoe 3520 or the releasable coupling 3600 include a third fluid passage 3555 fluidically coupled to the pressure chamber 3550 and the mud motor 3530.

The shoe 3520 may comprise any number of conventional commercially available shoes such as, for example, cement filled, aluminum or composite modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the shoe 3520 comprises a high strength shoe having a burst strength approximately equal to the burst strength of the tubular member 3525 and mandrel launcher 3515. The shoe 3520 is preferably coupled to the mud motor 3520 by a releasable coupling 3600 in order to optimally provide for removal of the mud motor 3530 and drill bit 3535 upon the completion of a drilling and casing operation.

In a preferred embodiment, the shoe 3520 includes a releasable latch mechanism 3600 for retrieving and removing the mud motor 3530 and drill bit 3535 upon the completion of the drilling and casing formation operations. In a preferred embodiment, the shoe 3520 further includes an anti-rotation device for maintaining the shoe 3520 in a substantially stationary rotational position during operation of the apparatus 3500. In a preferred embodiment, the releasable latch mechanism 3600 is releasably coupled to the shoe 3520.

The tubular member 3525 is supported by and coupled to the mandrel 3510. The tubular member 3525 is expanded in the radial direction and extruded off of the mandrel 3510. The tubular member 3525 may be fabricated from any number of conventional commercially available materials such as, for example, Oilfield Country Tubular Goods (OCTG), 13 chromium steel tubing/casing, automotive grade steel, or plastic tubing/casing. In a preferred embodiment, the tubular member 3525 is fabricated from OCTG in order to maximize strength after expansion. The inner and outer diameters of the tubular member 3525 may range,

WO 01/04535

PCT/US00/18635

for example, from approximately 0.75 to 47 inches and 1.05 to 48 inches, respectively. In a preferred embodiment, the inner and outer diameters of the tubular member 3525 range from about 3 to 15.5 inches and 3.5 to 16 inches, respectively in order to optimally provide minimal telescoping effect in the most  
5 commonly drilled wellbore sizes. The tubular member 3525 preferably comprises an annular member with solid walls.

In a preferred embodiment, the upper end portion 3580 of the tubular member 3525 is slotted, perforated, or otherwise modified to catch or slow down the mandrel 3510 when the mandrel 3510 completes the extrusion of tubular  
10 member 3525. For typical tubular member 3525 materials, the length of the tubular member 3525 is preferably limited to between about 40 to 20,000 feet in length. The tubular member 3525 may comprise a single tubular member or, alternatively, a plurality of tubular members coupled to one another.

The mud motor 3530 is coupled to the shoe 3520 and the drill bit 3535. The  
15 mud motor 3530 is also fluidically coupled to the fluid passage 3555. In a preferred embodiment, the mud motor 3530 is driven by fluidic materials such as, for example, drilling mud, water, cement, epoxy, lubricants or slag mix conveyed from the fluid passage 3555 to the mud motor 3530. In this manner, the mud motor 3530 drives the drill bit 3535. The operating pressures and flow rates for operating  
20 mud motor 3530 may range, for example, from about 0 to 12,000 psi and 0 to 10,000 gallons/minute. In a preferred embodiment, the operating pressures and flow rates for operating mud motor 3530 range from about 0 to 5,000 psi and 40 to 3,000 gallons/minute.

The mud motor 3530 may comprise any number of conventional  
25 commercially available mud motors, modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the size of the mud motor 3520 and drill bit 3535 are selected to pass through the interior of the shoe 3520 and the expanded tubular member 3525. In this manner, the mud motor 3520 and drill bit 3535 may be retrieved from the downhole location upon the conclusion of the  
30 drilling and casing operations.

WO 01/04535

PCT/US00/18635

The drill bit 3535 is coupled to the mud motor 3530. The drill bit 3535 is preferably adapted to be powered by the mud motor 3530. In this manner, the drill bit 3535 drills out new sections of the wellbore 3575.

The drill bit 3535 may comprise any number of conventional commercially available drill bits, modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the size of the mud motor 3520 and drill bit 3535 are selected to pass through the interior of the shoe 3520 and the expanded tubular member 3525. In this manner, the mud motor 3520 and drill bit 3535 may be retrieved from the downhole location upon the conclusion of the drilling and casing operations. In several alternative preferred embodiments, the drill bit 3535 comprises an eccentric drill bit, a bi-centered drill bit, or a small diameter drill bit with an hydraulically actuated under reamer.

The first fluid passage 3540 permits fluidic materials to be transported to the second fluid passage 3545, the pressure chamber 3550, the third fluid passage 3555, and the mud motor 3530. The first fluid passage 3540 is coupled to and positioned within the support member 3505. The first fluid passage 3540 preferably extends from a position adjacent to the surface to the second fluid passage 3545 within the mandrel 3510. The first fluid passage 3540 is preferably positioned along a centerline of the apparatus 3500.

The second fluid passage 3545 permits fluidic materials to be conveyed from the first fluid passage 3540 to the pressure chamber 3550, the third fluid passage 3555, and the mud motor 3530. The second fluid passage 3545 is coupled to and positioned within the mandrel 3510. The second fluid passage 3545 preferably extends from a position adjacent to the first fluid passage 3540 to the bottom of the mandrel 3510. The second fluid passage 3545 is preferably positioned substantially along the centerline of the apparatus 3500.

The pressure chamber 3550 permits fluidic materials to be conveyed from the second fluid passage 3545 to the third fluid passage 3555, and the mud motor 3530. The pressure chamber is preferably defined by the region below the mandrel 3510 and within the tubular member 3525, mandrel launcher 3515, shoe 3520, and releasable coupling 3600. During operation of the apparatus 3500, pressurization



WO 01/04535

PCT/US00/18635

of the pressure chamber 3550 preferably causes the tubular member 3525 to be extruded off of the mandrel 3510.

The third fluid passage 3555 permits fluidic materials to be conveyed from the pressure chamber 3550 to the mud motor 3530. The third fluid passage 3555  
5 may be coupled to and positioned within the shoe 3520 or releasable coupling 3600. The third fluid passage 3555 preferably extends from a position adjacent to the pressure chamber 3550 to the bottom of the shoe 3520 or releasable coupling 3600. The third fluid passage 3555 is preferably positioned substantially along the centerline of the apparatus 3500.

10 The fluid passages 3540, 3545, and 3555 are preferably selected to convey materials such as cement, drilling mud or epoxies at flow rates and pressures ranging from about 0 to 3,000 gallons/minute and 0 to 9,000 psi in order to optimally operational efficiency.

The cup seal 3560 is coupled to and supported by the outer surface of the  
15 support member 3505. The cup seal 3560 prevents foreign materials from entering the interior region of the tubular member 3525. The cup seal 3560 may comprise any number of conventional commercially available cup seals such as, for example, TP cups or SIP cups modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the cup seal 3560 comprises a SIP cup,  
20 available from Halliburton Energy Services in Dallas, TX in order to optimally block the entry of foreign materials and contain a body of lubricant. In a preferred embodiment, the apparatus 3500 includes a plurality of such cup seals in order to optimally prevent the entry of foreign material into the interior region of the tubular member 3525 in the vicinity of the mandrel 3510.

25 In a preferred embodiment, a quantity of lubricant 3565 is provided in the annular region above the mandrel 3510 within the interior of the tubular member 3525. In this manner, the extrusion of the tubular member 3525 off of the mandrel 3510 is facilitated. The lubricant 3565 may comprise any number of conventional commercially available lubricants such as, for example, Lubriplate,  
30 chlorine based lubricants, oil based lubricants or Climax 1500 Antisieze (3100). In a preferred embodiment, the lubricant 3565 comprises Climax 1500 Antisieze

WO 01/04535

PCT/US00/18635

(3100) available from Climax Lubricants and Equipment Co. in Houston, TX in order to optimally provide optimum lubrication to facilitate the expansion process.

The seals 3570 are coupled to and supported by the end portion 3580 of the tubular member 3525. The seals 3570 are further positioned on an outer surface  
5 of the end portion 3580 of the tubular member 3525. The seals 3570 permit the overlapping joint between the lower end portion 3585 of a preexisting section of casing 3590 and the end portion 3580 of the tubular member 3525 to be fluidically sealed. The seals 3570 may comprise any number of conventional commercially available seals such as, for example, lead, rubber, Teflon, or epoxy seals modified  
10 in accordance with the teachings of the present disclosure. In a preferred embodiment, the seals 3570 are molded from Stratalock epoxy available from Halliburton Energy Services in Dallas, TX in order to optimally provide a load bearing interference fit between the end 3580 of the tubular member 3525 and the end 3585 of the pre-existing casing 3590.

15 In a preferred embodiment, the seals 3570 are selected to optimally provide a sufficient frictional force to support the expanded tubular member 3525 from the pre-existing casing 3590. In a preferred embodiment, the frictional force optimally provided by the seals 3570 ranges from about 1,000 to 1,000,000 lbf in order to optimally support the expanded tubular member 3525.

20 The releasable coupling 3600 is preferably releasably coupled to the bottom of the shoe 3520. In a preferred embodiment, the releasable coupling 3600 includes fluidic seals for sealing the interface between the releasable coupling 3600 and the shoe 3520. In this manner, the pressure chamber 3550 may be pressurized. The releasable coupling 3600 may comprise any number of  
25 conventional commercially available releasable couplings suitable for drilling operations modified in accordance with the teachings of the present disclosure.

As illustrated in Figure 22A, during operation of the apparatus 3500, the apparatus 3500 is preferably initially positioned within a preexisting section of a wellbore 3575 including a preexisting section of wellbore casing 3590. In a  
30 preferred embodiment, the upper end portion 3580 of the tubular member 3525 is positioned in an overlapping relationship with the lower end 3585 of the preexisting section of casing 3590. In a preferred embodiment, the apparatus 3500

WO 01/04535

PCT/US00/18635

is initially positioned in the wellbore 3575 with the drill bit 353 in contact with the bottom of the wellbore 3575. During the initial placement of the apparatus 3500 in the wellbore 3575, the tubular member 3525 is preferably supported by the mandrel 3510.

5 As illustrated in Figure 22B, a fluidic material 3595 is then pumped into the first fluid passage 3540. The fluidic material 3595 is preferably conveyed from the first fluid passage 3540 to the second fluid passage 3545, the pressure chamber 3550, the third fluid passage 3555 and the inlet to the mud motor 3530. The fluidic material 3595 may comprise any number of conventional commercially  
10 available fluidic materials such as, for example, drilling mud, water, cement, epoxy or slag mix. The fluidic material 3595 may be pumped into the first fluid passage 3540 at operating pressures and flow rates ranging, for example, from about 0 to 9,000 psi and 0 to 3,000 gallons/minute.

The fluidic material 3595 will enter the inlet for the mud motor 3530 and  
15 drive the mud motor 3530. The fluidic material 3595 will then exit the mud motor 3530 and enter the annular region surrounding the apparatus 3500 within the wellbore 3575. The mud motor 3530 will in turn drive the drill bit 3535. The operation of the drill bit 3535 will drill out a new section of the wellbore 3575.

In the case where the fluidic material 3595 comprises a hardenable fluidic  
20 material, the fluidic material 3595 preferably is permitted to cure and form an outer annular body surrounding the periphery of the expanded tubular member 3525. Alternatively, in the case where the fluidic material 3595 is a non-hardenable fluidic material, the tubular member 3595 preferably is expanded into intimate contact with the interior walls of the wellbore 3575. In this manner, an  
25 outer annular body is not provided in all applications.

As illustrated in Figure 22C, at some point during operation of the mud motor 3530 and drill bit 3535, the pressure drop across the mud motor 3530 will create sufficient back pressure to cause the operating pressure within the pressure chamber 3550 to elevate to the pressure necessary to extrude the tubular member  
30 3525 off of the mandrel 3510. The elevation of the operating pressure within the pressure chamber 3550 will then cause the tubular member 3525 to extrude off of the mandrel 3510 as illustrated in Figure 22D. For typical tubular members 3525,

WO 01/04535

PCT/US00/18635

the necessary operating pressure may range, for example, from about 1,000 to 9,000 psi. In this manner, a wellbore casing is formed simultaneous with the drilling out of a new section of wellbore.

In a particularly preferred embodiment, during the operation of the apparatus 3500, the apparatus 3500 is lowered into the wellbore 3575 until the drill bit 3535 is proximate the bottom of the wellbore 3575. Throughout this process, the tubular member 3525 is preferably supported by the mandrel 3510. The apparatus 3500 is then lowered until the drill bit 3535 is placed in contact with the bottom of the wellbore 3575. At this point, at least a portion of the weight of the tubular member 3525 is supported by the drill bit 3535.

The fluidic material 3595 is then pumped into the first fluid passage 3540, second fluid passage 3545, pressure chamber 3550, third fluid passage 3555, and the inlet of the mud motor 3530. The mud motor 3530 then drives the drill bit 3535 to drill out a new section of the wellbore 3575. Once the differential pressure across the mud motor 3530 exceeds the minimum extrusion pressure for the tubular member 3525, the tubular member 3525 begins to extrude off of the mandrel 3510. As the tubular member 3525 is extruded off of the mandrel 3510, the weight of the extruded portion of the tubular member 3525 is transferred to and supported by the drill bit 3535. In a preferred embodiment, the pumping pressure of the fluidic material 3595 is maintained substantially constant throughout this process. At some point during the process of extruding the tubular member 3525 off of the mandrel 3510, a sufficient portion of the weight of the tubular member 3525 is transferred to the drill bit 3535 to stop the extrusion process due to the opposing force. Continued drilling by the drill bit 3535 eventually transfers a sufficient portion of the weight of the extruded portion of the tubular member 3525 back to the mandrel 3510. At this point, the extrusion of the tubular member 3525 off of the mandrel 3510 continues. In this manner, the support member 3505 never has to be moved and no drillpipe connections have to be made at the surface since the new section of the wellbore casing within the newly drilled section of wellbore is created by the constant downward feeding of the expanded tubular member 3525 off of the mandrel 3510.

WO 01/04535

PCT/US00/18635

Once the new section of wellbore that is lined with the fully expanded tubular member 3525 is completed, the support member 3505 and mandrel 3510 are removed from the wellbore 3575. The drilling assembly including the mud motor 3530 and drill bit 3535 are then preferably removed by lowering a drillstring  
5 into the new section of wellbore casing and retrieving the drilling assembly by using the latch 3600. The expanded tubular member 3525 is then cemented using conventional squeeze cementing methods to provide a solid annular sealing member around the periphery of the expanded tubular member 3525.

Alternatively, the apparatus 3500 may be used to repair or form an  
10 underground pipeline or form a support member for a structure. In several preferred alternative embodiments, the teachings of the apparatus 3500 are combined with the teachings of the embodiments illustrated in Figures 1-21. For example, by operably coupling the mud motor 3530 and drill bit 3535 to the pressure chambers used to cause the radial expansion of the tubular members of  
15 the embodiments illustrated and described with reference to Figures 1-21, the use of plugs may be eliminated and radial expansion of tubular members can be combined with the drilling out of new sections of wellbore.

Referring now to FIGS. 23A, 23B and 23C, an apparatus 3700 for expanding a tubular member will be described. In a preferred embodiment, the apparatus  
20 3700 includes a support member 3705, a packer 3710, a first fluid conduit 3715, an annular fluid passage 3720, fluid inlets 3725, an annular seal 3730, a second fluid conduit 3735, a fluid passage 3740, a mandrel 3745, a mandrel launcher 3750, a tubular member 3755, slips 3760, and seals 3765. In a preferred embodiment, the apparatus 3700 is used to radially expand the tubular member 3755. In this  
25 manner, the apparatus 3700 may be used to form a wellbore casing, line a wellbore casing, form a pipeline, line a pipeline, form a structural support member, or repair a wellbore casing, pipeline or structural support member. In a preferred embodiment, the apparatus 3700 is used to clad at least a portion of the tubular member 3755 onto a preexisting tubular member.

30 The support member 3705 is preferably coupled to the packer 3710 and the mandrel launcher 3750. The support member 3705 preferably comprises a tubular member fabricated from any number of conventional commercially available

WO 01/04535

PCT/US00/18635

materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, or stainless steel. The support member 3705 is preferably selected to fit through a preexisting section of wellbore casing 3770. In this manner, the apparatus 3700 may be positioned within the wellbore casing 3770. In a preferred  
5 embodiment, the support member 3705 is releasably coupled to the mandrel launcher 3750. In this manner, the support member 3705 may be decoupled from the mandrel launcher 3750 upon the completion of an extrusion operation.

The packer 3710 is coupled to the support member 3705 and the first fluid conduit 3715. The packer 3710 preferably provides a fluid seal between the  
10 outside surface of the first fluid conduit 3715 and the inside surface of the support member 3705. In this manner, the packer 3710 preferably seals off and, in combination with the support member 3705, first fluid conduit 3715, second fluid conduit 3735, and mandrel 3745, defines an annular chamber 3775. The packer 3710 may comprise any number of conventional commercially available packers  
15 modified in accordance with the teachings of the present disclosure.

The first fluid conduit 3715 is coupled to the packer 3710 and the annular seal 3730. The first fluid conduit 3715 preferably comprises an annular member fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, or  
20 stainless steel. In a preferred embodiment, the first fluid conduit 3715 includes one or more fluid inlets 3725 for conveying fluidic materials from the annular fluid passage 3720 into the chamber 3775.

The annular fluid passage 3720 is defined by and positioned between the interior surface of the first fluid conduit 3715 and the interior surface of the  
25 second fluid conduit 3735. The annular fluid passage 3720 is preferably adapted to convey fluidic materials such as cement, water, epoxy, lubricants, and slag mix at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute in order to optimally provide operational efficiency.

The fluid inlets 3725 are positioned in an end portion of the first fluid  
30 conduit 3715. The fluid inlets 3725 preferably are adapted to convey fluidic materials such as cement, water, epoxy, lubricants, and slag mix at operating

WO 01/04535

PCT/US00/18635

pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute in order to optimally provide operational efficiency.

The annular seal 3730 is coupled to the first fluid conduit 3715 and the second fluid conduit 3735. The annular seal 3730 preferably provides a fluid seal  
5 between the interior surface of the first fluid conduit 3715 and the exterior surface of the second fluid conduit 3735. The annular seal 3730 preferably provides a fluid seal between the interior surface of the first fluid conduit 3715 and the exterior surface of the second fluid conduit 3735 during relative axial motion of the first fluid conduit 3715 and the second fluid conduit 3735. The annular seal 3730 may  
10 comprise any number of conventional commercially available seals such as, for example, o-rings, polypak seals or metal spring energized seals. In a preferred embodiment, the annular seal 3730 comprises a polypak seal available from Parker Seals in order to optimally provide sealing for axial motion.

The second fluid conduit 3735 is coupled to the annular seal 3730 and the  
15 mandrel 3745. The second fluid conduit preferably comprises a tubular member fabricated from any number of conventional commercially available materials such as, for example, coiled tubing, oilfield country tubular goods, low alloy steel, stainless steel, or low carbon steel. In a preferred embodiment, the second fluid conduit 3735 is adapted to convey fluidic materials such as cement, water, epoxy,  
20 lubricants, and slag mix at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute in order to optimally provide operational efficiency.

The fluid passage 3740 is coupled to the second fluid conduit 3735 and the mandrel 3745. In a preferred embodiment, the fluid passage 3740 is adapted to  
25 convey fluidic materials such as cement, water, epoxy, lubricants, and slag mix at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute in order to optimally provide operational efficiency.

The mandrel 3745 is coupled to the second fluid conduit 3735 and the mandrel launcher 3750. The mandrel 3745 preferably comprise an annular  
30 member having a conic section fabricated from any number of conventional commercially available materials such as, for example, carbon steel, tool steel, ceramics, or composite materials. In a preferred embodiment, the angle of attack

WO 01/04535

PCT/US00/18635

the conic section of the mandrel 3745 ranges from about 10 to 30 degrees in order to optimally expand the mandrel launcher 3750 and tubular member 3755 in the radial direction. In a preferred embodiment, the surface hardness of the conic section of the mandrel 3745 ranges from about 50 Rockwell C to 70 Rockwell C.

- 5 In a particularly preferred embodiment, the surface hardness of the outer surface of the conic section of the mandrel 3745 ranges from about 58 Rockwell C to 62 Rockwell C in order to optimally provide high yield strength. In an alternative embodiment, the mandrel 3745 is expandable in order to further optimally augment the radial expansion process.

- 10 The mandrel launcher 3750 is coupled to the support member 3705, the mandrel 3745, and the tubular member 3755. The mandrel launcher 3750 preferably comprise a tubular member having a variable cross-section and a reduced wall thickness in order to facilitate the radial expansion process. In a preferred embodiment, the cross-sectional area of the mandrel launcher 3750 at  
15 one end is adapted to mate with the mandrel 3745, and at the other end, the cross-sectional area of the mandrel launcher 3750 is adapted to match the cross-sectional area of the tubular member 3755. In a preferred embodiment, the wall thickness of the mandrel launcher 3750 ranges from about 50 to 100 % of the wall thickness of the tubular member 3755 in order to facilitate the initiation of the radial  
20 expansion process.

- The mandrel launcher 3750 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low allow steel, stainless steel, or carbon steel. In a preferred embodiment, the mandrel launcher 3750 is fabricated from oilfield  
25 country tubular goods having higher strength but lower wall thickness than the tubular member 3755 in order to optimally match the burst strength of the tubular member 3755. In a preferred embodiment, the mandrel launcher 3750 is removably coupled to the tubular member 3755. In this manner, the mandrel launcher 3750 may be removed from the wellbore 3780 upon the completion of an  
30 extrusion operation.

The tubular member 3755 is coupled to the mandrel launcher, the slips 3760 and the seals 3765. The tubular member 3755 preferably comprises a tubular



WO 01/04535

PCT/US00/18635

member fabricated from any number of conventional commercially available materials such as, for example, low alloy steel, carbon steel, stainless steel, or oilfield country tubular goods. In a preferred embodiment, the tubular member 3755 is fabricated from oilfield country tubular goods.

5           The slips 3760 are coupled to the outside surface of the tubular member 3755. The slips 3760 preferably are adapted to couple to the interior walls of a casing, pipeline or other structure upon the radial expansion of the tubular member 3755. In this manner, the slips 3760 provide structural support for the expanded tubular member 3755. The slips 3760 may comprise any number of  
10 conventional commercially available slips, modified in accordance with the teachings of the present disclosure.

          The seals 3765 are coupled to the outside surface of the tubular member 3755. The seals 3765 preferably provide a fluidic seal between the outside surface of the expanded tubular member 3755 and the interior walls of a casing, pipeline  
15 or other structure upon the radial expansion of the tubular member 3755. In this manner, the seals 3765 provide a fluidic seal for the expanded tubular member 3755. The seals 3765 may comprise any number of conventional commercially available seals such as, for example, lead, rubber, Teflon or epoxy seals modified in accordance with the teachings of the present disclosure. In a preferred  
20 embodiment, the seals 3765 comprise seals molded from Stratalock epoxy available from Halliburton Energy Services in Dallas, TX in order to optimally provide a hydraulic seal in the overlapping joint and optimally provide load carrying capacity to withstand the range of typical tensile and compressive loads.

          During operation of the apparatus 3700, the apparatus 3700 is preferably  
25 lowered into a wellbore 3780 having a preexisting section of wellbore casing 3770. In a preferred embodiment, the apparatus 3700 is positioned with at least a portion of the tubular member 3755 overlapping with a portion of the wellbore casing 3770. In this manner, the radial expansion of the tubular member 3755 will preferably cause the outside surface of the expanded tubular member 3755 to  
30 couple with the inside surface of the wellbore casing 3770. In a preferred embodiment, the radial expansion of the tubular member 3755 will also cause the slips 3760 and seals 3765 to engage with the interior surface of the wellbore casing

WO 01/04535

PCT/US00/18635

3770. In this manner, the expanded tubular member 3755 is provided with enhanced structural support by the slips 3760 and an enhanced fluid seal by the seals 3765.

As illustrated in FIG. 23B, after placement of the apparatus 3700 in an overlapping relationship with the wellbore casing 3770, a fluidic material 3785 is preferably pumped into the chamber 3775 using the fluid passage 3720 and the inlet passages 3725. In a preferred embodiment, the fluidic material is pumped into the chamber 3775 at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute in order to optimally provide operational efficiency. The pumped fluidic material 3785 increase the operating pressure within the chamber 3775. The increased operating pressure in the chamber 3775 then causes the mandrel 3745 to extrude the mandrel launcher 3750 and tubular member 3755 off of the face of the mandrel 3745. The extrusion of the mandrel launcher 3750 and tubular member 3755 off of the face of the mandrel 3745 causes the mandrel launcher 3750 and tubular member 3755 to expand in the radial direction. Continued pumping of the fluidic material 3785 preferably causes the entire length of the tubular member 3755 to expand in the radial direction.

In a preferred embodiment, the pumping rate and pressure of the fluidic material 3785 is reduced during the latter stages of the extrusion process in order to minimize shock to the apparatus 3700. In a preferred embodiment, the apparatus 3700 includes shock absorbers for absorbing the shock caused by the completion of the extrusion process.

In a preferred embodiment, the extrusion process causes the mandrel 3745 to move in an axial direction 3785. During the axial movement of the mandrel, in a preferred embodiment, the fluid passage 3740 conveys fluidic material 3790 displaced by the moving mandrel 3745 out of the wellbore 3780. In this manner, the operational efficiency and speed of the extrusion process is enhanced.

In a preferred embodiment, the extrusion process includes the injection of a hardenable fluidic material into the annular region between the tubular member 3755 and the bore hole 3780. In this manner, a hardened sealing layer is provided between the expanded tubular member 3755 and the interior walls of the wellbore 3780.

WO 01/04535

PCT/US00/18635

As illustrated in FIG. 23C, in a preferred embodiment, upon the completion of the extrusion process, the support member 3705, packer 3710, first fluid conduit 3715, annular seal 3730, second fluid conduit 3735, mandrel 3745, and mandrel launcher 3750 are moved from the wellbore 3780.

5 In an alternative embodiment, the apparatus 3700 is used to repair a preexisting wellbore casing, pipeline, or structural support. In this alternative embodiment, both ends of the tubular member 3755 preferably include slips 3760 and seals 3765.

10 In an alternative embodiment, the apparatus 3700 is used to form a tubular structural support for a building or offshore structure.

Referring now to FIGS. 24A, 24B, 24C, 24D, and 24E, an apparatus 3900 for expanding a tubular member will be described. In a preferred embodiment, the apparatus 3900 includes a support member 3905, a mandrel launcher 3910, a mandrel 3915, a first fluid passage 3920, a tubular member 3925, slips 3930, seals 15 3935, a shoe 3940, and a second fluid passage 3945. In a preferred embodiment, the apparatus 3900 is used to radially expand the mandrel launcher 3910 and tubular member 3925. In this manner, the apparatus 3900 may be used to form a wellbore casing, line a wellbore casing, form a pipeline, line a pipeline, form a structural support member, or repair a wellbore casing, pipeline or structural 20 support member. In a preferred embodiment, the apparatus 3900 is used to clad at least a portion of the tubular member 3925 onto a preexisting structural member.

The support member 3905 is preferably coupled to the mandrel launcher 3910. The support member 3905 preferably comprises a tubular member 25 fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low alloy steel, carbon steel, or stainless steel. The support member 3905, the mandrel launcher 3910, the tubular member 3925, and the shoe 3940 are preferably selected to fit through a preexisting section of wellbore casing 3950. In this manner, the apparatus 3900 30 may be positioned within the wellbore casing 3970. In a preferred embodiment, the support member 3905 is releasably coupled to the mandrel launcher 3910. In

WO 01/04535

PCT/US00/18635

this manner, the support member 3905 may be decoupled from the mandrel launcher 3910 upon the completion of an extrusion operation.

The mandrel launcher 3910 is coupled to the support member 3905 and the tubular member 3925. The mandrel launcher 3910 preferably comprise a tubular member having a variable cross-section and a reduced wall thickness in order to facilitate the radial expansion process. In a preferred embodiment, the cross-sectional area of the mandrel launcher 3910 at one end is adapted to mate with the mandrel 3915, and at the other end, the cross-sectional area of the mandrel launcher 3910 is adapted to match the cross-sectional area of the tubular member 3925. In a preferred embodiment, the wall thickness of the mandrel launcher 3910 ranges from about 50 to 100 % of the wall thickness of the tubular member 3925 in order to facilitate the initiation of the radial expansion process.

The mandrel launcher 3910 may be fabricated from any number of conventional commercially available materials such as, for example, oilfield country tubular goods, low allow steel, stainless steel, or carbon steel. In a preferred embodiment, the mandrel launcher 3910 is fabricated from oilfield country tubular goods having higher strength but lower wall thickness than the tubular member 3925 in order to optimally match the burst strength of the tubular member 3925. In a preferred embodiment, the mandrel launcher 3910 is removably coupled to the tubular member 3925. In this manner, the mandrel launcher 3910 may be removed from the wellbore 3960 upon the completion of an extrusion operation.

The mandrel 3915 is coupled to the mandrel launcher 3910. The mandrel 3915 preferably comprise an annular member having a conic section fabricated from any number of conventional commercially available materials such as, for example, tool steel, carbon steel, ceramics, or composite materials. In a preferred embodiment, the angle of attack of the conic section of the mandrel 3915 ranges from about 10 to 30 degrees in order to optimally expand the mandrel launcher 3910 and the tubular member 3925 in the radial direction. In a preferred embodiment, the surface hardness of the conic section of the mandrel 3915 ranges from about 58 to 62 Rockwell C in order to optimally provide high strength and

WO 01/04535

PCT/US00/18635

resist wear and galling. In an alternative embodiment, the mandrel 3915 is expandable in order to further optimally augment the radial expansion process.

The fluid passage 3920 is positioned within the mandrel 3915. The fluid passage 3920 is preferably adapted to convey fluidic materials such as cement, 5 water, epoxy, lubricants, and slag mix at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute in order to optimally provide operational efficiency. The fluid passage 3920 preferably includes an inlet 3965 adapted to receive a plug, or other similar device. In this manner, the interior chamber 3970 above the mandrel 3915 may be fluidically 10 isolated from the interior chamber 3975 below the mandrel 3915.

The tubular member 3925 is coupled to the mandrel launcher 3910, the slips 3930 and the seals 3935. The tubular member 3925 preferably comprises a tubular member fabricated from any number of conventional commercially available materials such as, for example, low alloy steel, carbon steel, stainless steel, or 15 oilfield country tubular goods. In a preferred embodiment, the tubular member 3925 is fabricated from oilfield country tubular goods.

The slips 3930 are coupled to the outside surface of the tubular member 3925. The slips 3930 preferably are adapted to couple to the interior walls of a casing, pipeline or other structure upon the radial expansion of the tubular 20 member 3925. In this manner, the slips 3930 provide structural support for the expanded tubular member 3925. The slips 3930 may comprise any number of conventional commercially available slips, modified in accordance with the teachings of the present disclosure.

The seals 3935 are coupled to the outside surface of the tubular member 25 3925. The seals 3935 preferably provide a fluidic seal between the outside surface of the expanded tubular member 3925 and the interior walls of a casing, pipeline or other structure upon the radial expansion of the tubular member 3925. In this manner, the seals 3935 provide a fluidic seal for the expanded tubular member 3925. The seals 3935 may comprise any number of conventional commercially 30 available seals such as, for example, lead, rubber or epoxy. In a preferred embodiment, the seals 3935 comprise Stratalok epoxy material available from

WO 01/04535

PCT/US00/18635

Halliburton Energy Services in order to optimally provide structural support for the typical tensile and compressive loads.

The shoe 3940 is coupled to the tubular member 3925. The shoe 3940 preferably comprises a substantially tubular member having a fluid passage 3945  
5 for conveying fluidic materials from the chamber 3975 to the annular region 3970 outside of the apparatus 3900. The shoe 3940 may comprise any number of conventional commercially available shoes modified in accordance with the teachings of the present disclosure.

During operation of the apparatus 3900, the apparatus 3900 is preferably  
10 lowered into a wellbore 3960 having a preexisting section of wellbore casing 3975. In a preferred embodiment, the apparatus 3900 is positioned with at least a portion of the tubular member 3925 overlapping with a portion of the wellbore casing 3975. In this manner, the radial expansion of the tubular member 3925 will preferably cause the outside surface of the expanded tubular member 3925 to  
15 couple with the inside surface of the wellbore casing 3975. In a preferred embodiment, the radial expansion of the tubular member 3925 will also cause the slips 3930 and seals 3935 to engage with the interior surface of the wellbore casing 3975. In this manner, the expanded tubular member 3925 is provided with enhanced structural support by the slips 3930 and an enhanced fluid seal by the  
20 seals 3935.

As illustrated in FIG. 24B, after placement of the apparatus 3900 in an overlapping relationship with the wellbore casing 3975, a fluidic material 3980 is preferably pumped into the chamber 3970. The fluidic material 3980 then passes through the fluid passage 3920 into the chamber 3975. The fluidic material 3980  
25 then passes out of the chamber 3975, through the fluid passage 3945, and into the annular region 3970. In a preferred embodiment, the fluidic material 3980 is pumped into the chamber 3970 at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000 gallons/minute in order to optimally provide operational efficiency. In a preferred embodiment, the fluidic material 3980  
30 comprises a hardenable fluidic sealing material in order to form a hardened outer annular member around the expanded tubular member 3925.

WO 01/04535

PCT/US00/18635

As illustrated in FIG. 24C, at some later point in the process, a ball 3985, plug or other similar device, is introduced into the pumped fluidic material 3980. In a preferred embodiment, the ball 3985 mates with and seals off the inlet 3965 of the fluid passage 3920. In this manner, the chamber 3970 is fluidically isolated  
5 from the chamber 3975.

As illustrated in FIG. 24D, after placement of the ball 3985 in the inlet 3965 of the fluid passage 3920, a fluidic material 3990 is pumped into the chamber 3970. The fluidic material is preferably pumped into the chamber 3970 at operating pressures and flow rates ranging from about 0 to 9,000 psi and 0 to 3,000  
10 gallons/minute in order to provide optimal operating efficiency. The fluidic material 3990 may comprise any number of conventional commercially available materials such as, for example, water, drilling mud, cement, epoxy, or slag mix. In a preferred embodiment, the fluidic material 3990 comprises a non-hardenable fluidic material in order to maximize operational efficiency.

Continued pumping of the fluidic material 3990 increases fluidic material  
15 3980 increases the operating pressure within the chamber 3970. The increased operating pressure in the chamber 3970 then causes the mandrel 3915 to extrude the mandrel launcher 3910 and tubular member 3925 off of the conical face of the mandrel 3915. The extrusion of the mandrel launcher 3910 and tubular member  
20 3925 off of the conical face of the mandrel 3915 causes the mandrel launcher 3910 and tubular member 3925 to expand in the radial direction. Continued pumping of the fluidic material 3990 preferably causes the entire length of the tubular member 3925 to expand in the radial direction.

In a preferred embodiment, the pumping rate and pressure of the fluidic  
25 material 3990 is reduced during the latter stages of the extrusion process in order to minimize shock to the apparatus 3900. In a preferred embodiment, the apparatus 3900 includes shock absorbers for absorbing the shock caused by the completion of the extrusion process. In a preferred embodiment, the extrusion process causes the mandrel 3915 to move in an axial direction 3995.

As illustrated in FIG. 24E, in a preferred embodiment, upon the completion  
30 of the extrusion process, the support member 3905, packer 3910, first fluid conduit 3915, annular seal 3930, second fluid conduit 3935, mandrel 3945, and mandrel

WO 01/04535

PCT/US00/18635

launcher 3950 are removed from the wellbore 3980. In a preferred embodiment, the resulting new section of wellbore casing includes the preexisting wellbore casing 3975, the expanded tubular member 3925, the slips 3930, the seals 3935, the shoe 3940, and an outer annular layer 4000 of hardened fluidic material.

5 In an alternative embodiment, the apparatus 3900 is used to repair a preexisting wellbore casing or pipeline. In this alternative embodiment, both ends of the tubular member 3955 preferably include slips 3960 and seals 3965.

In an alternative embodiment, the apparatus 3900 is used to form a tubular structural support for a building or offshore structure.

10 Referring to FIGS. 25 and 26, the optimal relationship between the angle of attack of an expansion mandrel and the minimally required propagation pressure during the expansion of a tubular member will now be described. As illustrated in FIG. 25, during the radial expansion of a tubular member 4100 by an expansion mandrel 4105, the expansion mandrel 4105 is displaced in the axial  
15 direction. The angle of attack  $\alpha$  of the conical surface 4110 of the expansion mandrel 4105 directly affects the required propagation pressure  $P_{PR}$  necessary to radially expand the tubular member 4100. Referring to FIG. 26, for typical grades of materials and typical geometries, the propagation pressure  $P_{PR}$  is minimized for an angle of attack of approximately 25 degrees. Furthermore, the optimal range  
20 of the angle of attack  $\alpha$  ranges from about 10 to 30 degrees in order to minimize the range of required minimum propagation pressure  $P_{PR}$ .

Referring to FIG. 27, an embodiment of an expandable threaded connection 4300 will now be described. The expandable threaded connection 4300 preferably includes a first tubular member 4305, a second tubular member 4310, a threaded  
25 connection 4315, an O-ring groove 4320, and an O-ring 4325.

The first tubular member 4305 includes an inside wall 4330 and an outside wall 4335. The first tubular member 4305 preferably comprises an annular member having a substantially constant wall thickness. The second tubular member 4310 includes an inside wall 4340 and an outside wall 4345. The second  
30 tubular member 4310 preferably comprises an annular member having a substantially constant wall thickness.



WO 01/04535

PCT/US00/18635

The first and second tubular members, 4305 and 4310, may comprise any number of conventional commercially available members. In a preferred embodiment, the inside and outside diameters of the first and second tubular members, 4305 and 4310, are substantially equal. In this manner, the burst  
5 strength of the tubular members, 4305 and 4310, are substantially equal. This minimizes the possibility of a catastrophic failure during the radial expansion process.

The threaded connection 4315 may comprise any number of conventional threaded connections suitable for use with tubular members. In a preferred  
10 embodiment, the threaded connection 4315 comprises a pin-and-box threaded connection. In this manner, the assembly of the first tubular member 4305 to the second tubular member 4310 is optimized.

The O-ring groove 4320 is preferably provided in the threaded portion of the interior wall 4340 of the second tubular member 4310. The O-ring groove 4320 is  
15 preferably adapted to receive and support one or more O-rings. The volumetric size of the O-ring groove 4320 is preferably selected to permit the O-ring 4325 to expand at least approximately 20% in the axial direction during the radial expansion process. In this manner, deformation of the outer surface 4345 of the second tubular member 4310 during and upon the completion of the radial  
20 expansion process is minimized.

The O-ring 4325 is supported by the O-ring groove 4320. The O-ring 4325 optimally ensures that a fluid-tight seal is maintained between the first tubular member 4305 and the second tubular member 4310 throughout and upon the completion of the radial expansion process.

25 Referring to FIG. 28, an alternative embodiment of an expandable threaded connection 4500 will now be described. The expandable threaded connection 4500 includes a first tubular member 4505, a second tubular member 4510, a threaded connection 4515, an O-ring groove 4520, and an O-ring 4525.

The first tubular member 4505 includes an inside wall 4530 and an outside  
30 wall 4535. The first tubular member 4305 preferably comprises an annular member having a substantially constant wall thickness. The second tubular member 4510 includes an inside wall 4540 and an outside wall 4545. The second

WO 01/04535

PCT/US00/18635

tubular member 4510 preferably comprises an annular member having a substantially constant wall thickness.

The first and second tubular members, 4505 and 4510, may comprise any number of conventional commercially available members. In a preferred embodiment, the inside and outside diameters of the first and second tubular members, 4505 and 4510, are substantially equal. In this manner, the burst strength of the tubular members, 4505 and 4510, are substantially equal. This minimizes the possibility of a catastrophic failure during the radial expansion process.

10 The threaded connection 4515 may comprise any number of conventional threaded connections suitable for use with tubular members. In a preferred embodiment, the threaded connection 4515 comprises a pin-and-box threaded connection. In this manner, the assembly of the first tubular member 4505 to the second tubular member 4510 is optimized.

15 The O-ring groove 4520 is preferably provided in the threaded portion of the interior wall 4540 of the second tubular member 4510 immediately adjacent to an end portion of the threaded connection 4515. In this manner, the sealing effect provided by the O-ring 4525 is optimized. The O-ring groove 4520 is preferably adapted to receive and support one or more O-rings. The volumetric size of the O-ring groove 4520 is preferably selected to permit the O-ring 4525 to expand at least approximately 20% in the axial direction during the radial expansion process. In this manner, deformation of the outer surface 4545 of the second tubular member 4510 during and upon the completion of the radial expansion process is minimized.

25 The O-ring 4525 is supported by the O-ring groove 4520. The O-ring 4525 optimally ensures that a fluid-tight seal is maintained between the first tubular member 4505 and the second tubular member 4510 throughout and upon the completion of the radial expansion process.

Referring to FIG. 29, an alternative embodiment of an expandable threaded connection 4700 will now be described. The expandable threaded connection 4700 includes a first tubular member 4705, a second tubular member 4710, a threaded

30

WO 01/04535

PCT/US00/18635

connection 4715, an O-ring groove 4720, a first O-ring 4725, and a second O-ring 4730.

The first tubular member 4705 includes an inside wall 4735 and an outside wall 4740. The first tubular member 4705 preferably comprises an annular member having a substantially constant wall thickness. The second tubular member 4710 includes an inside wall 4745 and an outside wall 4750. The second tubular member 4710 preferably comprises an annular member having a substantially constant wall thickness.

The first and second tubular members, 4705 and 4710, may comprise any number of conventional commercially available members. In a preferred embodiment, the inside and outside diameters of the first and second tubular members, 4705 and 4710, are substantially equal. In this manner, the burst strength of the tubular members, 4705 and 4710, are substantially equal. This minimizes the possibility of a catastrophic failure during the radial expansion process.

The threaded connection 4715 may comprise any number of conventional threaded connections suitable for use with tubular members. In a preferred embodiment, the threaded connection 4715 comprises a pin-and-box threaded connection. In this manner, the assembly of the first tubular member 4705 to the second tubular member 4710 is optimized.

The O-ring groove 4720 is preferably provided in the threaded portion of the interior wall 4745 of the second tubular member 4710 immediately adjacent to an end portion of the threaded connection 4715. In this manner, the sealing effect provided by the O-rings, 4725 and 4730, is optimized. The O-ring groove 4720 is preferably adapted to receive and support a plurality of O-rings. The volumetric size of the O-ring groove 4720 is preferably selected to permit the O-rings, 4725 and 4730, to expand at least approximately 20% in the axial direction during the radial expansion process. In this manner, deformation of the outer surface 4750 of the second tubular member 4710 during and upon the completion of the radial expansion process is minimized.

The O-rings, 4725 and 4730, are supported by the O-ring groove 4720. The pair of O-rings, 4725 and 4730, optimally ensure that a fluid-tight seal is

WO 01/04535

PCT/US00/18635

maintained between the first tubular member 4705 and the second tubular member 4710 throughout and upon the completion of the radial expansion process. In particular, the use of a pair of adjacent O-rings provides redundancy in the seal between the first tubular member 4705 and the second tubular member 4710.

5 Referring to FIG. 30, an alternative embodiment of an expandable threaded connection 4900 will now be described. The expandable threaded connection 4900 includes a first tubular member 4905, a second tubular member 4910, a threaded connection 4915, a first O-ring groove 4920, a second O-ring groove 4925, a first O-ring 4930, and a second O-ring 4935.

10 The first tubular member 4905 includes an inside wall 4940 and an outside wall 4945. The first tubular member 4905 preferably comprises an annular member having a substantially constant wall thickness. The second tubular member 4910 includes an inside wall 4950 and an outside wall 4955. The second tubular member 4910 preferably comprises an annular member having a  
15 substantially constant wall thickness.

The first and second tubular members, 4905 and 4910, may comprise any number of conventional commercially available tubular members. In a preferred embodiment, the inside and outside diameters of the first and second tubular members, 4905 and 4910, are substantially equal. In this manner, the burst  
20 strength of the tubular members, 4905 and 4910, are substantially equal. This minimizes the possibility of a catastrophic failure during the radial expansion process.

The threaded connection 4915 may comprise any number of conventional threaded connections suitable for use with tubular members. In a preferred  
25 embodiment, the threaded connection 4915 comprises a pin-and-box threaded connection. In this manner, the assembly of the first tubular member 4905 to the second tubular member 4910 is optimized.

The first O-ring groove 4920 is preferably provided in the threaded portion of the interior wall 4950 of the second tubular member 4910 that is separated from  
30 an end portion of the threaded connection 4915. In this manner, the sealing effect provided by the O-rings, 4930 and 4935, is optimized. The first O-ring groove 4920 is preferably adapted to receive and support one more O-rings. The

WO 01/04535

PCT/US00/18635

volumetric size of the first O-ring groove 4920 is preferably selected to permit the O-ring 4930 to expand at least approximately 20% in the axial direction during the radial expansion process. In this manner, deformation of the outer surface 4955 of the second tubular member 4910 during and upon the completion of the radial expansion process is minimized.

The second O-ring groove 4925 is preferably provided in the threaded portion of the interior wall 4950 of the second tubular member 4910 that is immediately adjacent to an end portion of the threaded connection 4915. In this manner, the sealing effect provided by the O-rings, 4930 and 4935, is optimized.

10 The second O-ring groove 4925 is preferably adapted to receive and support one more O-rings. The volumetric size of the second O-ring groove 4925 is preferably selected to permit the O-ring 4935 to expand at least approximately 20% in the axial direction during the radial expansion process. In this manner, deformation of the outer surface 4955 of the second tubular member 4910 during and upon the

15 completion of the radial expansion process is minimized.

The O-rings, 4930 and 4935, are supported by the O-ring grooves, 4920 and 4925. The use of a pair of O-rings, 4930 and 4935, that are axially separated optimally ensures that a fluid-tight seal is maintained between the first tubular member 4905 and the second tubular member 4910 throughout and upon the

20 completion of the radial expansion process. In particular, the use of a pair of O-rings provides redundancy in the seal between the first tubular member 4905 and the second tubular member 4910.

In a preferred embodiment, the expandable threaded connections 4300, 4500, 4700, and/or 4900 are used in combination with one or more of the

25 embodiments illustrated in FIGS. 1-24E in order to optimally expand a plurality of tubular members coupled end to end using the expandable threaded connections 4300, 4500, 4700 and/or 4900.

Referring to FIG. 31, the lubrication of the interface between an expansion mandrel and a tubular member during the radial expansion process will now be

30 described. As illustrated in FIG. 31, during the radial expansion process, an expansion cone 5000 radially expands a tubular member 5005 by moving in an axial direction 5010 relative to the tubular member 5005. The interface between

WO 01/04535

PCT/US00/18635

the outer surface 5010 of the tapered portion 5015 of the expansion cone 5000 and the inner surface 5020 of the tubular member 5005 includes a leading edge portion 5025 and a trailing edge portion 5030.

During the radial expansion process, the leading edge portion 5025 is preferably lubricated by the presence of lubricating fluids provided ahead of the expansion cone 5000. However, because the radial clearance between the expansion cone 5000 and the tubular member 5005 in the trailing edge portion 5030 during the radial expansion process is typically extremely small, and the operating contact pressures between the tubular member 5005 and the expansion mandrel 5000 are extremely high, the quantity of lubricating fluid provided to the trailing edge portion 5030 is typically greatly reduced. In typical radial expansion operations, this reduction in lubrication in the trailing edge portion 5030 increases the forces required to radially expand the tubular member 5005.

Referring to FIG. 32, an embodiment of a system for lubricating the interface between an expansion cone and a tubular member during the expansion process will now be described. As illustrated in FIG. 32, an expansion cone 5100, having a front end 5100a and a rear end 5100b, includes a tapered portion 5105 having an outer surface 3110, one or more circumferential grooves 5115a and 5115b, and one or more internal flow passages 5120a and 5120b.

In a preferred embodiment, the circumferential grooves 5115 are fluidically coupled to the internal flow passages 5120. In this manner, during the radial expansion process, lubricating fluids are transmitted from the area ahead of the front 5100a of the expansion cone 5100 into the circumferential grooves 5115. Thus, the trailing edge portion of the interface between the expansion cone 5100 and a tubular member is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member. In a preferred embodiment, the lubricating fluids are injected into the internal flow passages 5120 using a fluid conduit that is coupled to the tapered end 5105 of the expansion cone 5100. Alternatively, lubricating fluids are provided for the internal flow passages 5120 using a supply of lubricating fluids provided adjacent to the front 5100a of the expansion cone 5100.

WO 01/04535

PCT/US00/18635

In a preferred embodiment, the expansion cone 5100 includes a plurality of circumferential grooves 5115. In a preferred embodiment, the cross sectional area of the circumferential grooves 5115 range from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$  in order to optimally provide lubrication to the trailing edge portion of the interface  
5 between the expansion cone 5100 and a tubular member during the radial expansion process. In a preferred embodiment, the expansion cone 5100 includes ... circumferential grooves 5115 concentrated about the axial midpoint of the tapered portion 5105 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5100 and a tubular member during  
10 the radial expansion process. In a preferred embodiment, the circumferential grooves 5115 are equally spaced along the trailing edge portion of the expansion cone 5100 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5100 and a tubular member during the radial expansion process.

15 In a preferred embodiment, the expansion cone 5100 includes a plurality of flow passages 5120 coupled to each of the circumferential grooves 5115. In a preferred embodiment, the cross-sectional area of the flow passages 5120 ranges from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$  in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5100 and a  
20 tubular member during the radial expansion process. In a preferred embodiment, the cross sectional area of the circumferential grooves 5115 is greater than the cross sectional area of the flow passage 5120 in order to minimize resistance to fluid flow.

Referring to FIG. 33, another embodiment of a system for lubricating the  
25 interface between an expansion cone and a tubular member during the expansion process will now be described. As illustrated in FIG. 33, an expansion cone 5200, having a front end 5200a and a rear end 5200b, includes a tapered portion 5205 having an outer surface 5210, one or more circumferential grooves 5215a and 5215b, and one or more axial grooves 5220a and 5220b.

30 In a preferred embodiment, the circumferential grooves 5215 are fluidically coupled to the axial grooves 5220. In this manner, during the radial expansion process, lubricating fluids are transmitted from the area ahead of the front 5200a

WO 01/04535

PCT/US00/18635

of the expansion cone 5200 into the circumferential grooves 5215. Thus, the trailing edge portion of the interface between the expansion cone 5200 and a tubular member is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member. In a preferred embodiment, the axial grooves 5220 are provided with lubricating fluid using a supply of lubricating fluid positioned proximate the front end 5200a of the expansion cone 5200. In a preferred embodiment, the circumferential grooves 3215 are concentrated about the axial midpoint of the tapered portion 5205 of the expansion cone 5200 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5200 and a tubular member during the radial expansion process. In a preferred embodiment, the circumferential grooves 5215 are equally spaced along the trailing edge portion of the expansion cone 5200 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5200 and a tubular member during the radial expansion process.

In a preferred embodiment, the expansion cone 5200 includes a plurality of circumferential grooves 5215. In a preferred embodiment, the cross sectional area of the circumferential grooves 5215 range from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$  in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5200 and a tubular member during the radial expansion process.

In a preferred embodiment, the expansion cone 5200 includes a plurality of axial grooves 5220 coupled to each of the circumferential grooves 5215. In a preferred embodiment, the cross sectional area of the axial grooves 5220 ranges from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$  in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5200 and a tubular member during the radial expansion process. In a preferred embodiment, the cross sectional area of the circumferential grooves 5215 is greater than the cross sectional area of the axial grooves 5220 in order to minimize resistance to fluid flow. In a preferred embodiment, the axial grooves 5220 are spaced apart in the circumferential direction by at least about 3 inches in order to optimally provide lubrication during the radial expansion process.



WO 01/04535

PCT/US00/18635

Referring to FIG. 34, another embodiment of a system for lubricating the interface between an expansion cone and a tubular member during the expansion process will now be described. As illustrated in FIG. 34, an expansion cone 5300, having a front end 5300a and a rear end 5300b, includes a tapered portion 5305  
5 having an outer surface 5310, one or more circumferential grooves 5315a and 5315b, and one or more internal flow passages 5320a and 5320b.

In a preferred embodiment, the circumferential grooves 5315 are fluidically coupled to the internal flow passages 5320. In this manner, during the radial expansion process, lubricating fluids are transmitted from the areas in front of the  
10 front 5300a and/or behind the rear 5300b of the expansion cone 5300 into the circumferential grooves 5315. Thus, the trailing edge portion of the interface between the expansion cone 5300 and a tubular member is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member. Furthermore, the lubricating fluids also  
15 preferably pass to the area in front of the expansion cone. In this manner, the area adjacent to the front 5300a of the expansion cone 5300 is cleaned of foreign materials. In a preferred embodiment, the lubricating fluids are injected into the internal flow passages 5320 by pressurizing the area behind the rear 5300b of the expansion cone 5300 during the radial expansion process.

20 In a preferred embodiment, the expansion cone 5300 includes a plurality of circumferential grooves 5315. In a preferred embodiment, the cross sectional area of the circumferential grooves 5315 ranges from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$  respectively, in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5300 and a tubular member during  
25 the radial expansion process. In a preferred embodiment, the expansion cone 5300 includes circumferential grooves 5315 that are concentrated about the axial midpoint of the tapered portion 5305 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5300 and a tubular member during the radial expansion process. In a preferred embodiment,  
30 the circumferential grooves 5315 are equally spaced along the trailing edge portion of the expansion cone 5300 in order to optimally provide lubrication to the trailing

WO 01/04535

PCT/US00/18635

edge portion of the interface between the expansion cone 5300 and a tubular member during the radial expansion process.

In a preferred embodiment, the expansion cone 5300 includes a plurality of flow passages 5320 coupled to each of the circumferential grooves 5315. In a preferred embodiment, the flow passages 5320 fluidically couple the front end 5300a and the rear end 5300b of the expansion cone 5300. In a preferred embodiment, the cross-sectional area of the flow passages 5320 ranges from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$  in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5300 and a tubular member during the radial expansion process. In a preferred embodiment, the cross sectional area of the circumferential grooves 5315 is greater than the cross-sectional area of the flow passages 5320 in order to minimize resistance to fluid flow.

Referring to FIG. 35, an embodiment of a system for lubricating the interface between an expansion cone and a tubular member during the expansion process will now be described. As illustrated in FIG. 35, an expansion cone 5400, having a front end 5400a and a rear end 5400b, includes a tapered portion 5405 having an outer surface 5410, one or more circumferential grooves 5415a and 5415b, and one or more axial grooves 5420a and 5420b.

In a preferred embodiment, the circumferential grooves 5415 are fluidically coupled to the axial grooves 5420. In this manner, during the radial expansion process, lubricating fluids are transmitted from the areas in front of the front 5400a and/or behind the rear 5400b of the expansion cone 5400 into the circumferential grooves 5415. Thus, the trailing edge portion of the interface between the expansion cone 5400 and a tubular member is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member. Furthermore, in a preferred embodiment, pressurized lubricating fluids pass from the fluid passages 5420 to the area in front of the front 5400a of the expansion cone 5400. In this manner, the area adjacent to the front 5400a of the expansion cone 5400 is cleaned of foreign materials. In a preferred embodiment, the lubricating fluids are injected into the internal flow passages 5420 by pressurizing the area behind the rear 5400b expansion cone 5400 during the radial expansion process.

WO 01/04535

PCT/US00/18635

In a preferred embodiment, the expansion cone 5400 includes a plurality of circumferential grooves 5415. In a preferred embodiment, the cross sectional area of the circumferential grooves 5415 range from about  $2 \times 10^{-4}$  in<sup>2</sup> to  $5 \times 10^{-2}$  in<sup>2</sup> in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5400 and a tubular member during the radial expansion process. In a preferred embodiment, the expansion cone 5400 includes circumferential grooves 5415 that are concentrated about the axial midpoint of the tapered portion 5405 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5400 and a tubular member during the radial expansion process. In a preferred embodiment, the circumferential grooves 5415 are equally spaced along the trailing edge portion of the expansion cone 5400 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5400 and a tubular member during the radial expansion process.

In a preferred embodiment, the expansion cone 5400 includes a plurality of axial grooves 5420 coupled to each of the circumferential grooves 5415. In a preferred embodiment, the axial grooves 5420 fluidically couple the front end and the rear end of the expansion cone 5400. In a preferred embodiment, the cross sectional area of the axial grooves 5420 range from about  $2 \times 10^{-4}$  in<sup>2</sup> to  $5 \times 10^{-2}$  in<sup>2</sup>, respectively, in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5400 and a tubular member during the radial expansion process. In a preferred embodiment, the cross sectional area of the circumferential grooves 5415 is greater than the cross sectional area of the axial grooves 5420 in order to minimize resistance to fluid flow. In a preferred embodiment, the axial grooves 5420 are spaced apart in the circumferential direction by at least about 3 inches in order to optimally provide lubrication during the radial expansion process.

Referring to FIG. 36, another embodiment of a system for lubricating the interface between an expansion cone and a tubular member during the expansion process will now be described. As illustrated in FIG. 36, an expansion cone 5500, having a front end 5500a and a rear end 5500b, includes a tapered portion 5505.

WO 01/04535

PCT/US00/18635

having an outer surface 5510, one or more circumferential grooves 5515a and 5515b, and one or more axial grooves 5520a and 5520b.

In a preferred embodiment, the circumferential grooves 5515 are fluidly coupled to the axial grooves 5520. In this manner, during the radial expansion process, lubricating fluids are transmitted from the area ahead of the front 5500a of the expansion cone 5500 into the circumferential grooves 5515. Thus, the trailing edge portion of the interface between the expansion cone 5500 and a tubular member is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member. In a preferred embodiment, the lubricating fluids are injected into the axial grooves 5520 using a fluid conduit that is coupled to the tapered end 3205 of the expansion cone 3200.

In a preferred embodiment, the expansion cone 5500 includes a plurality of circumferential grooves 5515. In a preferred embodiment, the cross sectional area of the circumferential grooves 5515 ranges from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$  in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5500 and a tubular member during the radial expansion process. In a preferred embodiment, the expansion cone 5500 includes circumferential grooves 5515 that are concentrated about the axial midpoint of the tapered portion 5505 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5500 and a tubular member during the radial expansion process. In a preferred embodiment, the circumferential grooves 5515 are equally spaced along the trailing edge portion of the expansion cone 5500 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5500 and a tubular member during the radial expansion process.

In a preferred embodiment, the expansion cone 5500 includes a plurality of axial grooves 5520 coupled to each of the circumferential grooves 5515. In a preferred embodiment, the axial grooves 5520 intersect each of the circumferential grooves 5515 at an acute angle. In a preferred embodiment, the cross sectional area of the axial grooves 5520 ranges from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$  in order to optimally provide lubrication to the trailing edge portion of the interface between

WO 01/04535

PCT/US00/18635

the expansion cone 5500 and a tubular member during the radial expansion process. In a preferred embodiment, the cross sectional area of the circumferential grooves 5515 is greater than the cross sectional area of the axial grooves 5520. In a preferred embodiment, the axial grooves 5520 are spaced apart in the circumferential direction by at least about 3 inches in order to optimally provide lubrication during the radial expansion process. In a preferred embodiment, the axial grooves 5520 intersect the longitudinal axis of the expansion cone 5500 at a larger angle than the angle of attack of the tapered portion 5505 in order to optimally provide lubrication during the radial expansion process.

Referring to FIG. 37, another embodiment of a system for lubricating the interface between an expansion cone and a tubular member during the expansion process will now be described. As illustrated in FIG. 37, an expansion cone 5600, having a front end 5600a and a rear end 5600b, includes a tapered portion 5605 having an outer surface 5610, a spiral circumferential groove 5615, and one or more internal flow passages 5620.

In a preferred embodiment, the circumferential groove 5615 is fluidically coupled to the internal flow passage 5620. In this manner, during the radial expansion process, lubricating fluids are transmitted from the area ahead of the front 5600a of the expansion cone 5600 into the circumferential groove 5615. Thus, the trailing edge portion of the interface between the expansion cone 5600 and a tubular member is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member. In a preferred embodiment, the lubricating fluids are injected into the internal flow passage 5620 using a fluid conduit that is coupled to the tapered end 5605 of the expansion cone 5600.

In a preferred embodiment, the expansion cone 5600 includes a plurality of spiral circumferential grooves 5615. In a preferred embodiment, the cross sectional area of the circumferential groove 5615 ranges from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$  in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5600 and a tubular member during the radial expansion process. In a preferred embodiment, the expansion cone 5600 includes circumferential grooves 5615 that are concentrated about the axial

WO 01/04535

PCT/US00/18635

midpoint of the tapered portion 5605 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5600 and a tubular member during the radial expansion process. In a preferred embodiment, the circumferential grooves 5615 are equally spaced along the trailing edge portion of the expansion cone 5600 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5600 and a tubular member during the radial expansion process.

In a preferred embodiment, the expansion cone 5600 includes a plurality of flow passages 5620 coupled to each of the circumferential grooves 5615. In a preferred embodiment, the cross-sectional area of the flow passages 5620 ranges from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$  in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5600 and a tubular member during the radial expansion process. In a preferred embodiment, the cross sectional area of the circumferential groove 5615 is greater than the cross sectional area of the flow passage 5620 in order to minimize resistance to fluid flow.

Referring to FIG. 38, another embodiment of a system for lubricating the interface between an expansion cone and a tubular member during the expansion process will now be described. As illustrated in FIG. 38, an expansion cone 5700, having a front end 5700a and a rear end 5700b, includes a tapered portion 5705 having an outer surface 5710, a spiral circumferential groove 5715, and one or more axial grooves 5720a, 5720b and 5720c.

In a preferred embodiment, the circumferential groove 5715 is fluidically coupled to the axial grooves 5720. In this manner, during the radial expansion process, lubricating fluids are transmitted from the area ahead of the front 5700a of the expansion cone 5700 into the circumferential groove 5715. Thus, the trailing edge portion of the interface between the expansion cone 5700 and a tubular member is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member. In a preferred embodiment, the lubricating fluids are injected into the axial grooves 5720 using a fluid conduit that is coupled to the tapered end 5705 of the expansion cone 5700.

WO 01/04535

PCT/US00/18635

In a preferred embodiment, the expansion cone 5700 includes a plurality of spiral circumferential grooves 5715. In a preferred embodiment, the cross sectional area of the circumferential grooves 5715 range from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$  in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5700 and a tubular member during the radial expansion process. In a preferred embodiment, the expansion cone 5700 includes circumferential grooves 5715 concentrated about the axial midpoint of the tapered portion 5705 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5700 and a tubular member during the radial expansion process. In a preferred embodiment, the circumferential grooves 5715 are equally spaced along the trailing edge portion of the expansion cone 5700 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5700 and a tubular member during the radial expansion process.

In a preferred embodiment, the expansion cone 5700 includes a plurality of axial grooves 5720 coupled to each of the circumferential grooves 5715. In a preferred embodiment, the cross sectional area of the axial grooves 5720 range from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$  in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5700 and a tubular member during the radial expansion process. In a preferred embodiment, the axial grooves 5720 intersect the circumferential grooves 5715 in a perpendicular manner. In a preferred embodiment, the cross sectional area of the circumferential groove 5715 is greater than the cross sectional area of the axial grooves 5720 in order to minimize resistance to fluid flow. In a preferred embodiment, the circumferential spacing of the axial grooves is greater than about 3 inches in order to optimally provide lubrication during the radial expansion process. In a preferred embodiment, the axial grooves 5720 intersect the longitudinal axis of the expansion cone at an angle greater than the angle of attack of the tapered portion 5705 in order to optimally provide lubrication during the radial expansion process.

Referring to FIG. 39, a preferred embodiment of a system for lubricating the interface between an expansion cone and a tubular member during the expansion

WO 01/04535

PCT/US00/18635

process will now be described. As illustrated in FIG. 39, an expansion cone 5800, having a front end 5800a and a rear end 5800b, includes a tapered portion 5805 having an outer surface 5810, a circumferential groove 5815, a first axial groove 5820, and one or more second axial grooves 5825a, 5825b, 5825c and 5825d.

5 In a preferred embodiment, the circumferential groove 5815 is fluidically coupled to the axial grooves 5820 and 5825. In this manner, during the radial expansion process, lubricating fluids are preferably transmitted from the area behind the back 5800b of the expansion cone 5800 into the circumferential groove 5815. Thus, the trailing edge portion of the interface between the expansion cone  
10 5800 and a tubular member is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member. In a preferred embodiment, the lubricating fluids are injected into the first axial groove 5820 by pressurizing the region behind the back 5800b of the expansion cone 5800. In a preferred embodiment, the lubricant is further  
15 transmitted into the second axial grooves 5825 where the lubricant preferably cleans foreign materials from the tapered portion 5805 of the expansion cone 5800.

In a preferred embodiment, the expansion cone 5800 includes a plurality of circumferential grooves 5815. In a preferred embodiment, the cross sectional area of the circumferential groove 5815 ranges from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$  in  
20 order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5800 and a tubular member during the radial expansion process. In a preferred embodiment, the expansion cone 5800 includes circumferential grooves 5815 concentrated about the axial midpoint of the tapered portion 5805 in order to optimally provide lubrication to the trailing edge portion  
25 of the interface between the expansion cone 5800 and a tubular member during the radial expansion process. In a preferred embodiment, the circumferential grooves 5815 are equally spaced along the trailing edge portion of the expansion cone 5800 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5800 and a tubular member during the  
30 radial expansion process.

In a preferred embodiment, the expansion cone 5800 includes a plurality of first axial grooves 5820 coupled to each of the circumferential grooves 5815. In a



WO 01/04535

PCT/US00/18635

preferred embodiment, the first axial grooves 5820 extend from the back 5800b of the expansion cone 5800 and intersect the circumferential groove 5815. In a preferred embodiment, the cross sectional area of the first axial groove 5820 ranges from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$  in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5800 and a tubular member during the radial expansion process. In a preferred embodiment, the first axial groove 5820 intersects the circumferential groove 5815 in a perpendicular manner. In a preferred embodiment, the cross sectional area of the circumferential groove 5815 is greater than the cross sectional area of the first axial groove 5820 in order to minimize resistance to fluid flow. In a preferred embodiment, the circumferential spacing of the first axial grooves 5820 is greater than about 3 inches in order to optimally provide lubrication during the radial expansion process.

In a preferred embodiment, the expansion cone 5800 includes a plurality of second axial grooves 5825 coupled to each of the circumferential grooves 5815. In a preferred embodiment, the second axial grooves 5825 extend from the front 5800a of the expansion cone 5800 and intersect the circumferential groove 5815. In a preferred embodiment, the cross sectional area of the second axial grooves 5825 ranges from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$  in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 5800 and a tubular member during the radial expansion process. In a preferred embodiment, the second axial grooves 5825 intersect the circumferential groove 5815 in a perpendicular manner. In a preferred embodiment, the cross sectional area of the circumferential groove 5815 is greater than the cross sectional area of the second axial grooves 5825 in order to minimize resistance to fluid flow. In a preferred embodiment, the circumferential spacing of the second axial grooves 5825 is greater than about 3 inches in order to optimally provide lubrication during the radial expansion process. In a preferred embodiment, the second axial grooves 5825 intersect the longitudinal axis of the expansion cone 5800 at an angle greater than the angle of attack of the tapered portion 5805 in order to optimally provide lubrication during the radial expansion process.

WO 01/04535

PCT/US00/18635

Referring to Fig. 40, in a preferred embodiment, the first axial groove 5820 includes a first portion 5905 having a first radius of curvature 5910, a second portion 5915 having a second radius of curvature 5920, and a third portion 5925 having a third radius of curvature 5930. In a preferred embodiment, the radius of 5 curvatures, 5910, 5920 and 5930 are substantially equal. In an exemplary embodiment, the radius of curvatures, 5910, 5920 and 5930 are all substantially equal to 0.0625 inches.

Referring to Fig. 41, in a preferred embodiment, the circumferential groove 5815 includes a first portion 6005 having a first radius of curvature 6010, a second 10 portion 6015 having a second radius of curvature 6020, and a third portion 6025 having a third radius of curvature 6030. In a preferred embodiment, the radius of curvatures, 6010, 6020 and 6030 are substantially equal. In an exemplary embodiment, the radius of curvatures, 6010, 6020 and 6030 are all substantially equal to 0.125 inches.

Referring to Fig. 42, in a preferred embodiment, the second axial groove 5825 includes a first portion 6105 having a first radius of curvature 6110, a second 15 portion 6115 having a second radius of curvature 6120, and a third portion 6125 having a third radius of curvature 6130. In a preferred embodiment, the first radius of curvature 6110 is greater than the third radius of curvature 6130. In an 20 exemplary embodiment, the first radius of curvature 6110 is equal to 0.5 inches, the second radius of curvature 6120 is equal to 0.0625 inches, and the third radius of curvature 6130 is equal to 0.125 inches.

Referring to Fig. 43, an embodiment of an expansion mandrel 6200 includes an internal flow passage 6205 having an insert 6210 including a flow passage 6215. 25 In a preferred embodiment, the cross sectional area of the flow passage 6215 is less than the cross sectional area of the flow passage 6215. More generally, in a preferred embodiment, a plurality of inserts 6210 are provided, each with different sizes of flow passages 6215. In this manner, the flow passage 6215 is machined to a standard size, and the lubricant supply is varied by using different sized inserts 30 6210. In a preferred embodiment, the teachings of the expansion mandrel 6200 are incorporated into the expansion mandrels 5100, 5300, and 5600.

WO 01/04535

PCT/US00/18635

Referring to Fig. 44, in a preferred embodiment, the insert 6210 includes a filter 6305 for filtering particles and other foreign materials from the lubricant that passes into the flow passage 6205. In this manner, the foreign materials are prevented from clogging the flow passage 6205 and other flow passages within the expansion mandrel 6200.

In a preferred embodiment, the one or more of the lubrication systems and elements of the mandrels 5100, 5200, 5300, 5400, 5500, 5600, 5700, 5800 and/or 5900 are incorporated into the methods and apparatus for expanding tubular members described above with reference to FIGS. 1-30. In this manner, the amount of force required to radially expand a tubular member in the formation and/or repair of a wellbore casing, pipeline, or structural support is significantly reduced. Furthermore, the increased lubrication provided to the trail edge portion of the mandrel greatly reduces the amount of galling or seizure caused by the interface between the mandrel and the tubular member during the radial expansion process thereby permitting larger continuous sections of tubulars to be radially expanded in a single continuous operation. Thus, use of the mandrels 5100, 5200, 5300, 5400, 5500, 5600, 5700, 5800 and/or 5900 reduces the operating pressures required for radial expansion and thereby reduces the sizes of the required hydraulic pumps and related equipment. In addition, failure, bursting, and/or buckling of tubular members during the radial expansion process is significantly reduced, and the success ratio of the radial expansion process is greatly increased.

In laboratory tests, a regular expansion cone, without any lubrication grooves and flow passages, and the expansion cone 5100 were both used to radially expand identical coiled tubular members, each having an outside diameter of 3 1/2 inches. The following tables summarizes the results of this laboratory test:

LUBRICATING FLUID	REGULAR EXPANSION CONE	EXPANSION CONE 5100
	FORCE REQUIRED TO EXPAND TUBULAR MEMBER	
PHPA Mud alone	78,000 lbf	72,000 lbf

WO 01/04535

PCT/US00/18635

PHPA Mud + 7% Lubricant Blend	48,000 lbf	46,000 lbf
100% Lubricant Blend	68,000 lbf	48,000 lbf

Where: PHPA Mud refers to a drilling mud mixture available from Baroid.

- 5 PHPA Mud + 7 % Lubricant Blend refers to a mixture of 93% PHPA Mud and 7% mixture of TorqTrim III, EP Mudlib, and DrillN-Slid available from Baroid.

100% Lubricant Blend refers to a mixture of TorqTrim III, EP Mudlib, and DrillN-Slid available from Baroid.

- 10 Thus, in an exemplary embodiment, the use of the expansion cone 5100 reduced the amount of force required to radially expand a tubular member by as much as 30%. This reduction in the required force translates to a corresponding reduction in the overall energy requirements as well as a reduction in the size of required operating equipment such as, for example, hydraulic pumping equipment.
- 15 During the course of a typical expansion operation, this results in tremendous cost savings to the operator.

In a preferred embodiment, the lubricating fluids used with the mandrels 5100, 5200, 5300, 5400, 5500, 5600, 5700, 5800 and 5900 for expanding tubular members have viscosities ranging from about 1 to 10,000 centipoise in order to

20 optimize the injection of the lubricating fluids into the circumferential grooves of the mandrels during the radial expansion process.

In a preferred embodiment, prior to placement in a wellbore, the outer surfaces of the apparatus for expanding tubular members described above with reference to FIGS. 1-30 are coated with a lubricating fluid to facilitate their

25 placement the wellbore and reduce surge pressures. In a preferred embodiment, the lubricating fluid comprises BARO-LUB GOLD-SEAL™ brand drilling mud

WO 01/04535

PCT/US00/18635

lubricant, available from Baroid Drilling Fluids, Inc. In this manner, the insertion of the apparatus into a wellbore, pipeline or other opening is optimized.

Referring to FIG. 45, a preferred embodiment of an expandible tubular 6400 for use in forming and/or repairing a wellbore casing, pipeline, or foundation support will now be described. In a preferred embodiment, the expandible tubular 6400 includes a wall thickness T.

In a preferred embodiment, the wall thickness T is substantially constant throughout the expandible tubular 6400. In a preferred embodiment, the variation in the wall thickness T about the circumference of the tubular member 6400 is less than about 8 % in order to optimally provide an expandible tubular 6400 having a substantially constant hoop yield strength.

In a preferred embodiment, the material composition of and the manufacturing processes used in forming the expandible tubular 6400 are selected to provide a hoop yield strength that varies less than about 10 % about the circumference of the tubular member 6400 in order to optimally provide consistent geometries in the expandible tubular 6400 after radial expansion.

In a preferred embodiment, the expandible tubular 6400 includes structural imperfections such as, for example, voids, foreign material, cracks, of less than about 5 % of the specified wall thickness T in order to optimize the radial expansion of the expandible tubular member 6400. In a preferred embodiment, each expandible tubular 6400 is tested for the presence of such defects using nondestructive testing methods in accordance with industry standard API SR2.

In a preferred embodiment, a representative sample of a selected group of tubular members 6400 are flared at one end using a conventional industry standard tubular flaring method, such as, for example the method disclosed in ASTM A450. As illustrated in Fig. 46, in a preferred embodiment, the walls of the flared end of the tubular member 6400 do not exhibit any necking for increases in the interior diameter of the flared end 6405 of the tubular member 6400 ranging from 0 to about 25%. As illustrated in Fig. 47, in a preferred embodiment, the flared end of the tubular member 6400 does not fail for increases in the interior diameter of the flared end of the tubular members 6400 ranging from 0 to at least about 30%. In this manner, a selected group of tubular members 6400 are

WO 01/04535

PCT/US00/18635

optimally selected for both necking and ductility properties subsequent to radial expansion.

Referring now to FIG. 48, a preferred embodiment of an expandable tubular member 6500 will now be described. The tubular member 6500 preferably includes a tubular body 6505 having an interior region 6510, an exterior surface 6515, a first end 6520 including a first expandable threaded connection 6525, an intermediate portion 6530, and a second end 6535 including a second expandable threaded connection 6540. The tubular member 6500 further preferably includes a first sealing member 6545, an intermediate sealing member 6550, and a second sealing member 6555. In a preferred embodiment, the tubular members 210, 715, 915, 1110, 1310, 1520, 1530, 1535, 1620, 1715, 1970, 2155, 2375, 2560, 2790, 3075, 3525, 3755, 3925, 4100, 5005, and 6400, described above with reference to FIGS. 1-47 comprise the tubular member 6500 in order to optimally provide an expanded tubular member for use in forming and/or repairing a wellbore casing, pipeline, or structural support. In a preferred embodiment, tubular members 210, 715, 915, 1110, 1310, 1520, 1530, 1535, 1620, 1715, 1970, 2155, 2375, 2560, 2790, 3075, 3525, 3755, 3925, 4100, 5005, and 6400, described above with reference to FIGS. 1-47, having wall thicknesses greater than about 0.25 inches are used for radial expansion operations, and the tubular member 6500 is used for all other radial expansion operations.

The tubular body 6505 of the tubular member 6500 preferably has a substantially annular cross section. The tubular body 6505 may be fabricated from any number of conventional commercially available materials such as, for example, Oilfield Country Tubular Goods (OCTG), 13 chromium steel tubing/casing, or L83, J55, or P110 API casing. In a preferred embodiment, the tubular body 6505 of the tubular member 6500 is selected using the teachings for selecting expandable tubular members described above with reference to FIGS. 45-47.

The interior region 6510 of the tubular body 6505 preferably has a substantially circular cross section. The interior region 6510 of the tubular body 6505 preferably includes a first inside diameter  $D_1$ , an intermediate inside diameter  $D_{INT}$ , and a second inside diameter  $D_2$ . In a preferred embodiment, the first and second inside diameters,  $D_1$  and  $D_2$ , are substantially equal. In a

- 265 -

preferred embodiment, the first and second inside diameters,  $D_1$  and  $D_2$ , are greater than the intermediate inside diameter  $D_{INT}$ .

The first end 6520 of the tubular body 6505 joined to the intermediate portion 6530 of the tubular body. The first end 6520 of the tubular body 6505 preferably includes the  
 5 first expandable threaded connection 6525 and the first sealing member 6545. In a preferred embodiment, the outside diameter of the first end 6520 of the tubular body 6505 is greater than the outside diameter of the intermediate portion 6530 of the tubular body 6530. In this manner, the intermediate sealing member 6550 is optimally protected during placement of the tubular member 6500 within a wellbore casing 6560. In a preferred  
 10 embodiment, the outside diameter of the first end 6520 of the tubular body 6505 is substantially equal to the outside diameter of the second end 6535 of the tubular body 6505. In this manner, the intermediate sealing member 6550 is optimally protected during placement of the tubular member 6500 within the wellbore casing 6560. In a preferred embodiment, the outside diameter of the first end 6520 of the tubular member 6505 is  
 15 adapted to permit insertion of the tubular member 6500 into the typical range of wellbore casings. The first end 6520 of the tubular member 6505 includes a wall thickness  $t_1$ .

The first expandable threaded connection 6525 is on the first end 6520 of the tubular body 6505. The first expandable threaded connection 6525 may comprise any number of conventional commercially available threaded connections suitable for radial  
 20 expansion. In a preferred embodiment, the first expandable threaded connection 6525 is provided in accordance with the teachings of the expandable threaded connections, 4300, 4500, 4700 and 4900, described above with reference to FIGS. 27-30. In a preferred embodiment, the first expandable threaded connection 6525 is adapted to mate with an adjacent second expandable threaded connection provided in an adjacent tubular member  
 25 6500. In this manner, a plurality of tubular members 6500 may be joined end to end.

The intermediate portion 6530 of the tubular body 6505 is joined to the first end 6520 of the tubular body 6505 and the second end 6535 of the tubular body 6505. The intermediate portion 6530 of the tubular body preferably includes the intermediate sealing member 6550. In a preferred embodiment, the outside diameter of the intermediate portion  
 30 6520 of the tubular body is less than the outside diameter of the first and second ends, 6520 and 6535, of the tubular body 6530. In this manner, the intermediate sealing member

- 266 -

6550 is optimally protected during placement of the tubular member 6500 within the wellbore casing 6560. In a preferred embodiment, the outside diameter of the intermediate portion 6530 of the tubular body 6505 ranges from about 75% to 98% of the outside diameters of the first and second ends, 6520 and 6535, in order to optimally protect the  
 5 intermediate sealing member 6550 during placement of the tubular member 6500 within the wellbore casing 6560. The intermediate portion 6530 of the tubular body includes a wall thickness  $t_{INT}$ .

The second end 6535 of the tubular body 6505 is joined to the intermediate portion 6530 of the tubular body. The second end 6520 of the tubular body 6505 preferably  
 10 includes the second expandable threaded connection 6540 and the second sealing member 6555. In a preferred embodiment, the outside diameter of the second end 6535 of the tubular body 6505 is greater than the outside diameter of the intermediate portion 6530 of the tubular body 6530. In this manner, the intermediate sealing member 6550 is optimally protected during placement of the tubular member 6500 within a wellbore casing 6560. In a preferred embodiment, the outside diameter of the second end 6535 of the tubular body  
 15 6505 is substantially equal to the outside diameter of the first end 6520 of the tubular body 6505. In this manner, the intermediate sealing member 6550 is optimally protected during placement of the tubular member 6500 within the wellbore casing 6560. In a preferred embodiment, the outside diameter of the second end 6535 of the tubular member 6505 is adapted to permit insertion of the tubular member 6500 into the typical range of wellbore casings. The second end 6535 of the tubular member 6505 includes a wall thickness  $t_2$ .  
 20

In a preferred embodiment, the wall thicknesses  $t_1$  and  $t_2$  are substantially equal in order to provide substantially equal burst strength for the first and second ends, 6520 and 6535, of the tubular member 6505. In a preferred embodiment, the wall thickness  $t_1$  and  $t_2$   
 25 are both greater than the wall thickness  $t_{INT}$  in order to optimally match the burst strength of the first and second ends, 6520 and 6535, of the tubular member 6505 with the intermediate portion 6530 of the tubular member 6505.

The second expandable threaded connection 6540 is on the second end 6535 of the tubular body 6505. The second expandable threaded connection 6540 may comprise any  
 30 number of conventional commercially available threaded connections suitable for radial expansion. In a preferred embodiment, the second expandable threaded connection 6540 is



- 267 -

provided in accordance with the teachings of the expandable threaded connections, 4300, 4500, 4700 and 4900, described above with reference to FIGS. 27-30. In a preferred embodiment, the second expandable threaded connection 6540 is adapted to mate with the adjacent first expandable threaded connection provided in an adjacent tubular member 5600. In this manner, a plurality of tubular members 6500 may be joined end to end.

The first sealing member 6545 is preferable on the outer surface 6515 of the first end 6520 of the tubular body 6505. The first sealing member 6545 preferably protects the first end 6520 of the tubular body 6505 during insertion of the tubular member 6500 into the wellbore 6560. The first sealing member 6545 further preferably seals the interface between the first end 6520 of the tubular body 6505 and interior surface of the wellbore 6560 after radial expansion of the first end 6520 of the tubular body 6505. The first sealing member 6545 preferably has a substantially annular cross section. The outside diameter of the first sealing member 6545 is preferably adapted to facilitate placement of the tubular member 6500 within the typical range of wellbore casings 6560. The first sealing member 6545 may be fabricated from any number of conventional commercially available materials such as, for example, polymer coatings or hard coatings. In a preferred embodiment, the first sealing member 6545 is fabricated from commercially available Armacor to optionally protect and seal the first end 6520 of the tubular body 6505.

The intermediate sealing member 6550 is preferably on the outer surface 6515 of the intermediate portion 6530 of the tubular body 6505. The intermediate sealing member 6550 preferably seals the interface between the intermediate portion 6530 of the tubular body 6505 and interior surface of the wellbore 6560 after radial expansion of the intermediate portion 6530 of the tubular body 6505. The intermediate sealing member 6550 preferably has a substantially annular cross section. The outside diameter of the intermediate sealing member 6550 is preferably selected to be less than the outside diameters of the first and second ends, 6520 and 6535, of the tubular body 6505 in order to optimally protect the intermediate sealing member 6550 during placement of the tubular member 6500 within the typical range of wellbore casings 6560. The intermediate sealing member 6550 may be fabricated from any number of conventional commercially available materials such as, for example, thermoset or thermoplastic polymers. In a preferred embodiment, the intermediate sealing member 6550 is fabricated from the thermoset

- 268 -

polymers in order to optimally seal the intermediate portion 6530 of the tubular body 6505.

The second sealing member 6555 is preferably on the outer surface 6515 of the second end 6535 of the tubular body 6505. The sealing member 6555 preferably protects the second end 6535 of the tubular body 6505 during insertion of the tubular member 6500 into the wellbore 6560. The second sealing member 6545 further preferably seals the interface between the second end 6535 of the tubular body 6505 and interior surface of the wellbore 6560 after radial expansion of the second end 6535 of the tubular body 6505. The second sealing member 6555 preferably has a substantially annular cross section. The outside diameter of the second sealing member 6555 is preferably adapted to facilitate placement of the tubular member 6500 within the typical range of wellbore casings 6560. The second sealing member 6555 may be fabricated from any number of conventional commercially available materials such as, for example, polymeric coatings or hard coatings. In a preferred embodiment, the second sealing member 6555 is fabricated from commercially available Armacor in order to optimally protect and seal the second end 6535 of the tubular body 6505.

During placement of the tubular member 6500 within the wellbore casing 6560, the first and second sealing members 6545 and 6555, preferably protect the outside surface 6515 of the first and second ends, 6520 and 6535, of the tubular body 6505 from abrasion with the interior surface of the wellbore casing 6560. In a preferred embodiment, after radial expansion of the tubular body 6505, the first, intermediate, and second sealing members, 6545, 6550 and 6555, preferably seal the interface between the outside surface 6515 of the tubular body 6505 of the tubular member 6500 and the inside surface of the wellbore casing 6560. During placement of the tubular member 6500 within the wellbore casing 6560, the intermediate sealing member 6550 is preferably protected from contact with the interior walls of the wellbore casing 6560 by the recessed outer surface profile of the tubular member 6500.

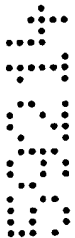
In a preferred embodiment, the tubular body 6505 further includes first and second transition portions, 6565 and 6570, between the first and second ends, 6520 and 6535, and the intermediate portion 6530 of the tubular body 6505. In a preferred embodiment, the first and second transition portions, 6565 and 6570, are inclined at an angle,  $\alpha$ , relative to the longitudinal direction ranging from about 0 to 30 degrees in order to optimally

- 269 -

facilitate the radial expansion of the tubular member 6500. In a preferred embodiment, the first and second transition portions, 6565 and 6570, provide a smooth transition between the first and second ends, 6520 and 6535, and the intermediate portion 6530, of the tubular member 6505 in order to minimise stress concentrations.

- 5 Referring to FIGS. 49, and 50a to 50e, in a preferred embodiment, the tubular member 6500 is formed by a process 6600. In a preferred embodiment, the process 6600 includes the steps of: (1) upsetting both ends of a tubular member in step 6605; (2) expanding both upset ends of the tubular member in step 6610; (3) stress relieving both expanded upset ends of the tubular member in step 6615; (4) forming expandable threaded
- 10 connections in both expanded upset ends of the tubular member in step 6620; (5) putting a protective coating of material on the outside diameter of the expanded ends of the tubular member in step 6625; and (6) putting a sealing material on the outside diameter of the non-expanded intermediate portion of the tubular member in step 6630.

- As illustrated in FIG 50a, in step 6605, both ends, 6705a and 6705b, of a tubular
- 15 member 6700 are upset using conventional upsetting methods. The upset ends, 6705a and 6705b, of the tubular member 6700 include wall thicknesses  $t_1$  and  $t_2$ . The intermediate portion 6610 of the tubular member 6700 includes a wall thickness  $t_{INT}$  and an interior diameter  $D_{INT}$ . In a preferred embodiment, the wall thicknesses  $t_1$  and  $t_2$  are substantially equal in order to provide burst strength that



WO 01/04535

PCT/US00/18635

is substantially equal along the entire length of the tubular member 6700. In a preferred embodiment, the wall thicknesses  $t_1$  and  $t_2$  are both greater than the wall thickness  $t_{INT}$  in order to provide burst strength that is substantially equal along the entire length of the tubular member 6700, and also to optimally facilitate the formation of threaded connections in the first and second ends, 6705a and 6705b.

As illustrated in FIG. 50b, in steps 6610 and 6615, both ends, 6705a and 6705b, of the tubular member 6700 are radially expanded using conventional radial expansion methods, and then both ends, 6705a and 6705b, of the tubular member are stress relieved. The radially expanded ends, 6705a and 6705b, of the tubular member 6700 include interior diameters  $D_1$  and  $D_2$ . In a preferred embodiment, the interior diameters  $D_1$  and  $D_2$  are substantially equal in order to provide a burst strength that is substantially equal. In a preferred embodiment, the ratio of the interior diameters  $D_1$  and  $D_2$  to the interior diameter  $D_{INT}$  ranges from about 100% to 120% in order to optimally provide a tubular member for subsequent radial expansion.

In a preferred embodiment, the relationship between the wall thicknesses  $t_1$ ,  $t_2$ , and  $t_{INT}$  of the tubular member 6700; the inside diameters  $D_1$ ,  $D_2$  and  $D_{INT}$  of the tubular member 6700; the inside diameter  $D_{wellbore}$  of the wellbore casing that the tubular member 6700 will be inserted into; and the outside diameter  $D_{cone}$  of the expansion cone that will be used to radially expand the tubular member 6700 within the wellbore casing is given by the following expression:

$$D_{wellbore} - 2 * t_1 \geq D_1 \geq \frac{1}{t_1} \left[ (t_1 - t_{INT}) * D_{cone} + t_{INT} * D_{INT} \right] \quad (1)$$

where  $t_1 = t_2$ ; and

$$D_1 = D_2$$

By satisfying the relationship given in equation (1), the expansion forces placed upon the tubular member 6700 during the subsequent radial expansion process are substantially equalized. More generally, the relationship given in equation (1) may be used to calculate the optimal geometry for the tubular member 6700 for subsequent radial expansion of the tubular member 6700 for fabricating and/or repairing a wellbore casing, a pipeline, or a structural support.

WO 01/04535

PCT/US00/18635

As illustrated in FIG. 50c, in step 6620, expandable threads 6715a and 6715b, are formed in both expanded ends, 6705a and 6705b, of the tubular member 6700. The expandable threads, 6715a and 6715b, may be formed in the expanded ends, 6705a and 6705b, of the tubular member 6700 using any number of  
5 conventional commercially available methods for forming expandable threads in a tubular member. In a preferred embodiment, the expandable threads, 6715a and 6715b, are provided in accordance with the teachings of the expandable threaded connections, 4300, 4500, 4700 and 4900, described above with reference to FIGS. 27-30, and are formed using conventional processes for forming pin and box type  
10 threaded connections available from Atlas-Bradford.

As illustrated in FIG. 50d, in step 6625, protective coatings, 6720a and 6720b, are then applied onto the outside diameters of the expanded ends, 6705a and 6705b, of the tubular member 6700. The protective coatings, 6720a and 6720b, may be applied to the outside diameters of the expanded ends, 6705a and  
15 6705b, of the tubular member 6700 using any number of conventional commercially available methods. In a preferred embodiment, the protective coatings, 6720a and 6720b, are applied to the outside diameters of the expanded ends, 6705a and 6705b, of the tubular member 6700 using commercially available chemical and temperature resistant adhesive bonding.

As illustrated in FIG. 50e, in step 6730, a sealing member 6725 is then applied onto the outside diameter of the non-expanded intermediate portion 6710 of the tubular member 6700. The sealing member 6725 may be applied to the outside diameter of the non-expanded intermediate portion 6710 of the tubular member 6700 using any number of conventional commercially available methods.  
20 In a preferred embodiment, the sealing member 6725 is applied to the outside diameter of the intermediate portion 6710 of the tubular member 6700 using commercially available chemical and temperature resistant adhesive bonding.

Referring to FIG. 51, a preferred embodiment of an expansion cone 6700 for radially expanding the tubular member 6500 will now be described. The expansion  
30 cone 6700 preferably includes a front end 6705, a rear end 6710, and a radial expansion section 6715. In a preferred embodiment, the expansion cone 6700 is used in one or more the embodiments of apparatus and methods for radially

WO 01/04535

PCT/US00/18635

expanding a tubular member described above with reference to FIGS. 1-47. In a preferred embodiment, when the expansion cone 6700 is displaced in the longitudinal direction relative to the tubular member 6500, the interaction of the exterior surface of the radial expansion section 6715 with the interior surface of the tubular member 6500 causes the tubular member 6500 to expand in the radial direction.

The radial expansion section 6715 preferably includes a first conical outer surface 6720 and a second conical outer surface 6725. The first conical outer surface 6720 includes an angle of attack  $\alpha_1$ , and the second conical outer surface 6725 includes an angle of attack  $\alpha_2$ . In a preferred embodiment, the angle of attack  $\alpha_1$  is greater than the angle of attack  $\alpha_2$ . In this manner, the first conical outer surface 6720 optimally radially overexpands the intermediate portion 6530 of the tubular member 6500 and the second conical outer surface 6725 optimally radially overexpands the pre-expanded first and second ends, 6520 and 6535, of the tubular member 6500. In a preferred embodiment, the first conical outer surface 6720 includes an angle of attack  $\alpha_1$  ranging from about 8 to 20 degrees. In a preferred embodiment, the second conical outer surface 6725 includes an angle of attack  $\alpha_2$  ranging from about 4 to 15 degrees. More generally, the expansion cone 6700 may include 3 or more adjacent conical outer surfaces having angles of attack that decrease from the front end 6705 of the expansion cone 6700 to the rear end 6710 of the expansion cone 6700.

Referring to FIG. 52, an alternative preferred embodiment of an expansion cone 6800 for radially expanding the tubular member 6500 will now be described. The expansion cone 6800 preferably includes a front end 6805, a rear end 6810, and a radial expansion section 6815. In a preferred embodiment, the expansion cone 6800 is used in one or more the embodiments of apparatus and methods for radially expanding a tubular member described above with reference to FIGS. 1-47. In a preferred embodiment, when the expansion cone 6800 is displaced in the longitudinal direction relative to the tubular member 6500, the interaction of the exterior surface of the radial expansion section 6815 with the interior surface of the tubular member 6500 causes the tubular member 6500 to expand in the radial direction.

WO 01/04535

PCT/US00/18635

The radial expansion section 6815 preferably includes an outer surface 6820 having a substantially parabolic outer profile. In this manner, the outer surface 6820 provides an angle of attack that constantly decreases from a maximum at the front end 6805 of the expansion cone 6800 to a minimum at the rear end 6810 of the expansion cone. The parabolic outer profile of the outer surface 6820 may be formed using a plurality of adjacent discrete conical sections and/or using a continuous curved surface. In this manner, the area of the outer surface 6820 adjacent to the front end 6805 of the expansion cone 6800 optimally radially overexpands the intermediate portion 6530 of the tubular member 6500, while the area of the outer surface 6820 adjacent to the rear end 6810 of the expansion cone 6800 optimally radially overexpands the pre-expanded first and second ends, 6520 and 6535, of the tubular member 6500. In a preferred embodiment, the parabolic profile of the outer surface 6820 is selected to provide an angle of attack that ranges from about 8 to 20 degrees in the vicinity of the front end 6805 of the expansion cone 6800 and an angle of attack in the vicinity of the rear end 6810 of the expansion cone 6800 from about 4 to 15 degrees.

Referring now to Figs 53a, 53b and 53c, an embodiment of a system for providing a wellbore casing having a substantially constant interior diameter will now be described. The system preferably provides a two-step process for forming a wellbore casing having a substantially constant interior diameter.

As illustrated in Fig. 53a, in a preferred embodiment, during the first step of the process for forming a wellbore casing having a substantially constant interior diameter, a wellbore casing 6900 is formed within a wellbore 6905 that includes a first tubular member 6910, an annular cement liner 6915, a second tubular member 6920, and one or more annular seals 6925. The upper end 6930 of the second tubular member 6920 and/or the annular seals 6925 are preferably radially expanded into intimate contact with the interior walls of the lower end 6935 of the first tubular member 6910 using one or more of the methods and apparatus described above, with reference to Figs. 1-52, for radially expanding a second tubular member into contact with a first tubular member. In a preferred embodiment, the inside diameter of the second tubular member 6920 is increased by about 2 to 50% during this first stage of the process.

WO 01/04535

PCT/US00/18635

As illustrated in Fig. 53b, in a preferred embodiment, during the second step of the process for forming a wellbore casing having a substantially constant interior diameter, an expansion assembly 6940 is positioned within the first tubular member 6910 above the upper end 6930 of the second tubular member 6920. In a preferred embodiment, the expansion assembly 6940 includes an expansion mandrel 6945, a support member 6950, a slip joint 6955, fluid conduit 6960, a packer 6965, a fluid conduit 6970, and a pump 6975.

The expansion mandrel 6945 is coupled to the support member 6950. The expansion mandrel 6945 is preferably adapted to radially expand the first and second tubular members, 6910 and 6920. In a preferred embodiment, the expansion mandrel 6945 further includes a pair of opposing tapered conical outer surfaces 6980a and 6980b in order to optimally facilitate placement of the expansion mandrel 6945 within the confines of the interior of the first tubular member 6910. In a preferred embodiment, the maximum outside diameter of the expansion mandrel 6945 is substantially equal to the inside diameter of the first tubular member 6910 in order to optimally radially expand the first and second tubular members, 6910 and 6920. In a preferred embodiment, the expansion mandrel 6945 incorporates one or more of the teachings of the present disclosure for optimizing the operational efficiency of an expansion mandrel.

The support member 6950 is preferably coupled to the expansion mandrel 6945, slidingly and sealingly coupled to the packer 6965, and supported by a conventional drilling rig positioned at a surface location. The support member 6950 is preferably adapted to support and position the expansion mandrel 6945 within the wellbore 6905. In a preferred embodiment, the support member 6950 further includes a conventional slip joint 6955 for slidingly coupling the expansion mandrel 6945 to the support member 6950. In a preferred embodiment, the slip joint 6955 permits the expansion mandrel 6945 to be displaced from about 15 to 30 feet in the axial direction relative to the support member 6950. The support member 6950 may comprise any number of conventional commercially available tubular support members modified in accordance with the teachings of the present disclosure.



WO 01/04535

PCT/US00/18635

The fluid conduit 6960 is coupled to and positioned within the expansion mandrel 6945 and the support member 6950. The fluid conduit 6960 is preferably adapted to convey fluidic materials located within the region 6985 below the expansion mandrel 6945 to a region above the packer 6965. In this manner, the  
5 axial displacement of the expansion mandrel 6945 is optimally facilitated.

The packer 6965 is sealingly coupled to the first tubular member 6910, sealingly coupled to the fluid conduit 6970, and sealingly and slidingly coupled to the support member 6950. The packer 6965 is preferably adapted to permit the support member 6950 to move in an axial direction, relative to the packer 6965,  
10 while also maintaining an operating pressure within an annular region 6990 between the top of the expansion mandrel 6945 and the bottom of the packer 6965 ranging up to about 15,000 psi. In this manner, the pressurization of the annular region 6990 is optimally facilitated. The packer 6965 may comprise any number of conventional commercially available packers modified in accordance with the  
15 teachings of the present disclosure. In a preferred embodiment, the packer 6965 is a 10,000 psi blowout preventor stack available from Cameron Iron Works.

The fluid conduit 6970 is fluidically coupled to the output of the pump 6975, sealingly coupled to the packer 6965, and fluidically coupled to the annular region 6990. The fluid conduit 6970 is preferably adapted to convey fluidic materials at  
20 operating pressures and flow rates ranging from about 500 to 15,000 psi and 0 to 1000 gallons/minute, respectively from the pump 6975 to the annular region 6990.

The output of the pump 6975 is fluidically coupled to the fluidic conduit 6970 and the input of the pump 6975 is fluidically coupled to a supply of fluidic materials. The pump 6975 is preferably adapted to convey fluidic materials at operating  
25 pressures and flow rates ranging from about 500 to 15,000 psi and 0 to 1,000 gallons/minute, respectively. The pump 6975 may comprise any number of conventional commercially available pumps modified in accordance with the teachings of the present disclosure. In a preferred embodiment, the pump 6975 is a HP-400 cement unit pump available from Halliburton.

30 In a preferred embodiment, during the second step of the process for forming a wellbore casing having a substantially constant interior diameter, the expansion mandrel 6945 is positioned above the upper end 6930 of the second

WO 01/04535

PCT/US00/18635

tubular member 6920. The packer 6965 is then activated and the annular region 6990 is sealed off. The pump 6975 is then activated and fluidic materials are pumped into the fluidic conduit 6970 for injection into the annular region 6990. In a preferred embodiment, the annular region 6990 is pressurized to operating pressures ranging from about 500 to 15,000 psi in order to optimally displace the expansion mandrel 6945 in the axial direction. Pressurization of the annular region 6990 preferably causes the expansion mandrel 6945 to be displaced in the axial direction. In a preferred embodiment, during axial displacement of the expansion mandrel 6945, the support member 6955 is substantially stationary and the expansion mandrel 6945 is displaced relative to the support member 6955 using the slip joint 6955. In an alternative preferred embodiment, the support member 6950 is axially displaced during axial displacement of the expansion mandrel 6945. In another alternative preferred embodiment, the slip joint 6955 is omitted and the support member 6950 is axially displaced during axial displacement of the expansion mandrel 6945.

During axial displacement of the expansion mandrel 6945, fluidic materials located in the region 6985 beneath the expansion mandrel 6945 are preferably conveyed to a region above the packer 6965 using the fluidic conduit 6960. In this manner, the axial displacement of the expansion mandrel 6945 is optimally facilitated. In a preferred embodiment, the axial displacement of the expansion mandrel 6945 is further increased by applying an axial force directly to the support member 6950.

In a preferred embodiment, during axial displacement of the expansion mandrel 6945, the interface between the support member 6950 and packer 6965 is preferably substantially sealed in order to maintain operating pressure within the annular region 6975. In an alternative preferred embodiment, during axial displacement of the expansion mandrel 6945 and support member 6950, the interface between the support member 6950 and packer 6965 is preferably substantially sealed in order to maintain operating pressure within the annular region 6975.

Once the radial expansion process is completed, the expansion mandrel 6945, support member 6950 and packer 6965 are removed from the wellbore 6905.

WO 01/04535

PCT/US00/18635

In an alternative embodiment, the expansion mandrel 6945 is pulled out of the wellbore 6905 with sufficient force to radially expand the first and/or second tubular members, 6910 and 6920. In this manner, any spring back by the first and/or second tubular member, 6910 and 6920, after the initial radial expansion  
5 by the expansion mandrel 6945 can be substantially eliminated.

As illustrated in Fig. 53c, the displacement of the expansion mandrel 6945 in the axial direction preferably radially expands both the first and second tubular members, 6910 and 6920, in the radial direction. In a preferred embodiment, after radial expansion of the first and second tubular members, 6910 and 6920, using  
10 the expansion assembly 6940, the interior diameters of the radially unexpanded portion of the first tubular member 6910 and the radially expanded portion of the second tubular member 6920 are substantially equal. In this manner, a wellbore casing is provided having a substantially constant interior diameter.

In an exemplary embodiment, the resulting overlapping joint formed by the  
15 interface between the radially expanded lower portion 6935 of the first tubular member 6910 and the radially expanded upper portion 6930 of the second tubular member 6920 provides a pressure seal rating that is greater than the pressure seal rating provided by a conventional threaded connection with O-rings provided between the first and second tubular members, 6910 and 6920. As will be  
20 recognized by persons having ordinary skill in the art, the pressure seal rating is a measure of the amount of fluid pressure that can be maintained by a sealing joint.

In an exemplary embodiment, the resulting overlapping joint formed by the interface between the radially expanded lower portion 6935 of the first tubular  
25 member 6910 and the radially expanded upper portion 6930 of the second tubular member 6920 provides a burst capacity that is greater than the individual burst capacities for the first tubular member 6910 and the second tubular member 6920. As will be recognized by persons having ordinary skill in the art, the burst capacity is the amount of internal pressure that can be contained by a pressure housing.

30

In an exemplary embodiment, the resulting overlapping joint formed by the interface between the radially expanded lower portion 6935 of the first tubular

WO 01/04535

PCT/US00/18635

member 6910 and the radially expanded upper portion 6930 of the second tubular member 6920 also has a tensile pullout rating that is greater than the individual tensile yield points for the first and second tubular members 6910 and 6920. As will be recognized by persons having ordinary skill in the art, the tensile pullout  
5 rating refers to the amount of tensile force required to pull apart a connection between two tubular members and the tensile yield point refers to the amount of tensile force required to cause a tubular member to yield.

In an exemplary embodiment, the resulting overlapping joint formed by the interface between the radially expanded lower portion 6935 of the first tubular  
10 member 6910 and the radially expanded upper portion 6930 of the second tubular member 6920 also provides a torsional failure point that is greater than the individual torsional yield points for the first and second tubular members 6910 and 6920. As will be recognized by persons having ordinary skill in the art, the torsional failure point refers to the amount of torque required to cause a  
15 connection between two tubular members to fail and the torsional yield point refers to the amount of torque required to cause a tubular member to yield.

Thus, a method of forming a wellbore casing having a substantially constant interior diameter is provided that preferably includes a two-step radial expansion process. In a preferred embodiment, during the first step of the process, the upper  
20 end 6930 of the second tubular member 6920 is expanded into contact with the lower end 6935 of the first tubular member 6910 using one or more of the methods described above with reference to Figs. 1-52. In a preferred embodiment, during the second step of the process, the expansion mandrel 6945 is axially displaced within, and relative to, the first and second tubular members, 6910 and 6920. As  
25 a result of the axial displacement of the expansion mandrel 6945, the first and second tubular members, 6910 and 6920, are preferably radially expanded. In a preferred embodiment, the interior diameters of the first and second tubular members, 6910 and 6920, are increased by about 0 to 50% during the second stage of the process. Furthermore, the interior diameters of the radially unexpanded  
30 portion of the first tubular member 6910 and the radially expanded portion of the second tubular member 6920 are preferably substantially equal.

WO 01/04535

PCT/US00/18635

In several alternative embodiments, the two-step process illustrated in Figs. 69a to 69c is used to repair and/or form a wellbore casing, a pipeline, or a structural support.

A method of creating a casing in a borehole located in a subterranean formation has been described that includes installing a tubular liner and a mandrel in the borehole. A body of fluidic material is then injected into the borehole. The tubular liner is then radially expanded by extruding the liner off of the mandrel. The injecting preferably includes injecting a hardenable fluidic sealing material into an annular region located between the borehole and the exterior of the tubular liner; and a non hardenable fluidic material into an interior region of the tubular liner below the mandrel. The method preferably includes fluidically isolating the annular region from the interior region before injecting the second quantity of the non hardenable sealing material into the interior region. The injecting the hardenable fluidic sealing material is preferably provided at operating pressures and flow rates ranging from about 0 to 5000 psi and 0 to 1,500 gallons/min. The injecting of the non hardenable fluidic material is preferably provided at operating pressures and flow rates ranging from about 500 to 9000 psi and 40 to 3,000 gallons/min. The injecting of the non hardenable fluidic material is preferably provided at reduced operating pressures and flow rates during an end portion of the extruding. The non hardenable fluidic material is preferably injected below the mandrel. The method preferably includes pressurizing a region of the tubular liner below the mandrel. The region of the tubular liner below the mandrel is preferably pressurized to pressures ranging from about 500 to 9,000 psi. The method preferably includes fluidically isolating an interior region of the tubular liner from an exterior region of the tubular liner. The method further preferably includes curing the hardenable sealing material, and removing at least a portion of the cured sealing material located within the tubular liner. The method further preferably includes overlapping the tubular liner with an existing wellbore casing. The method further preferably includes sealing the overlap between the tubular liner and the existing wellbore casing. The method further preferably includes supporting the extruded tubular liner using the overlap with the existing wellbore casing. The method further preferably includes testing the integrity of the seal in

WO 01/04535

PCT/US00/18635

the overlap between the tubular liner and the existing wellbore casing. The method further preferably includes removing at least a portion of the hardenable fluidic sealing material within the tubular liner before curing. The method further preferably includes lubricating the surface of the mandrel. The method further  
5 preferably includes absorbing shock. The method further preferably includes catching the mandrel upon the completion of the extruding.

An apparatus for creating a casing in a borehole located in a subterranean formation has been described that includes a support member, a mandrel, a tubular member, and a shoe. The support member includes a first fluid passage.  
10 The mandrel is coupled to the support member and includes a second fluid passage. The tubular member is coupled to the mandrel. The shoe is coupled to the tubular liner and includes a third fluid passage. The first, second and third fluid passages are operably coupled. The support member preferably further includes a pressure relief passage, and a flow control valve coupled to the first fluid passage and the  
15 pressure relief passage. The support member further preferably includes a shock absorber. The support member preferably includes one or more sealing members adapted to prevent foreign material from entering an interior region of the tubular member. The mandrel is preferably expandable. The tubular member is preferably fabricated from materials selected from the group consisting of Oilfield  
20 Country Tubular Goods, 13 chromium steel tubing/casing, and plastic casing. The tubular member preferably has inner and outer diameters ranging from about 3 to 15.5 inches and 3.5 to 16 inches, respectively. The tubular member preferably has a plastic yield point ranging from about 40,000 to 135,000 psi. The tubular member preferably includes one or more sealing members at an end portion. The  
25 tubular member preferably includes one or more pressure relief holes at an end portion. The tubular member preferably includes a catching member at an end portion for slowing down the mandrel. The shoe preferably includes an inlet port coupled to the third fluid passage, the inlet port adapted to receive a plug for blocking the inlet port. The shoe preferably is drillable.

30 A method of joining a second tubular member to a first tubular member, the first tubular member having an inner diameter greater than an outer diameter of the second tubular member, has been described that includes positioning a

WO 01/04535

PCT/US00/18635

mandrel within an interior region of the second tubular member, positioning the first and second tubular members in an overlapping relationship, pressurizing a portion of the interior region of the second tubular member; and extruding the second tubular member off of the mandrel into engagement with the first tubular member. The pressurizing of the portion of the interior region of the second tubular member is preferably provided at operating pressures ranging from about 500 to 9,000 psi. The pressurizing of the portion of the interior region of the second tubular member is preferably provided at reduced operating pressures during a latter portion of the extruding. The method further preferably includes sealing the overlap between the first and second tubular members. The method further preferably includes supporting the extruded first tubular member using the overlap with the second tubular member. The method further preferably includes lubricating the surface of the mandrel. The method further preferably includes absorbing shock.

15 A liner for use in creating a new section of wellbore casing in a subterranean formation adjacent to an already existing section of wellbore casing has been described that includes an annular member. The annular member includes one or more sealing members at an end portion of the annular member, and one or more pressure relief passages at an end portion of the annular member.

20 A wellbore casing has been described that includes a tubular liner and an annular body of a cured fluidic sealing material. The tubular liner is formed by the process of extruding the tubular liner off of a mandrel. The tubular liner is preferably formed by the process of placing the tubular liner and mandrel within the wellbore, and pressurizing an interior portion of the tubular liner. The annular body of the cured fluidic sealing material is preferably formed by the process of injecting a body of hardenable fluidic sealing material into an annular region external of the tubular liner. During the pressurizing, the interior portion of the tubular liner is preferably fluidically isolated from an exterior portion of the tubular liner. The interior portion of the tubular liner is preferably pressurized to pressures ranging from about 500 to 9,000 psi. The tubular liner preferably overlaps with an existing wellbore casing. The wellbore casing preferably further includes a seal positioned in the overlap between the tubular liner and the existing

WO 01/04535

PCT/US00/18635

wellbore casing. Tubular liner is preferably supported the overlap with the existing wellbore casing.

A method of repairing an existing section of a wellbore casing within a borehole has been described that includes installing a tubular liner and a mandrel  
5 within the wellbore casing, injecting a body of a fluidic material into the borehole, pressurizing a portion of an interior region of the tubular liner, and radially expanding the liner in the borehole by extruding the liner off of the mandrel. In a preferred embodiment, the fluidic material is selected from the group consisting of slag mix, cement, drilling mud, and epoxy. In a preferred embodiment, the  
10 method further includes fluidically isolating an interior region of the tubular liner from an exterior region of the tubular liner. In a preferred embodiment, the injecting of the body of fluidic material is provided at operating pressures and flow rates ranging from about 500 to 9,000 psi and 40 to 3,000 gallons/min. In a preferred embodiment, the injecting of the body of fluidic material is provided at  
15 reduced operating pressures and flow rates during an end portion of the extruding. In a preferred embodiment, the fluidic material is injected below the mandrel. In a preferred embodiment, a region of the tubular liner below the mandrel is pressurized. In a preferred embodiment, the region of the tubular liner below the mandrel is pressurized to pressures ranging from about 500 to 9,000 psi. In a  
20 preferred embodiment, the method further includes overlapping the tubular liner with the existing wellbore casing. In a preferred embodiment, the method further includes sealing the interface between the tubular liner and the existing wellbore casing. In a preferred embodiment, the method further includes supporting the extruded tubular liner using the existing wellbore casing. In a preferred  
25 embodiment, the method further includes testing the integrity of the seal in the interface between the tubular liner and the existing wellbore casing. In a preferred embodiment, method further includes lubricating the surface of the mandrel. In a preferred embodiment, the method further includes absorbing shock. In a preferred embodiment, the method further includes catching the  
30 mandrel upon the completion of the extruding. In a preferred embodiment, the method further includes expanding the mandrel in a radial direction.



WO 01/04535

PCT/US00/18635

A tie-back liner for lining an existing wellbore casing has been described that includes a tubular liner and an annular body of a cured fluidic sealing material. The tubular liner is formed by the process of extruding the tubular liner off of a mandrel. The annular body of a cured fluidic sealing material is coupled  
5 to the tubular liner. In a preferred embodiment, the tubular liner is formed by the process of placing the tubular liner and mandrel within the wellbore, and pressurizing an interior portion of the tubular liner. In a preferred embodiment, during the pressurizing, the interior portion of the tubular liner is fluidically isolated from an exterior portion of the tubular liner. In a preferred embodiment, the  
10 interior portion of the tubular liner is pressurized at pressures ranging from about 500 to 9,000 psi. In a preferred embodiment, the annular body of a cured fluidic sealing material is formed by the process of injecting a body of hardenable fluidic sealing material into an annular region between the existing wellbore casing and the tubular liner. In a preferred embodiment, the tubular liner overlaps with  
15 another existing wellbore casing. In a preferred embodiment, the tie-back liner further includes a seal positioned in the overlap between the tubular liner and the other existing wellbore casing. In a preferred embodiment, tubular liner is supported by the overlap with the other existing wellbore casing.

An apparatus for expanding a tubular member has been described that  
20 includes a support member, a mandrel, a tubular member, and a shoe. The support member includes a first fluid passage. The mandrel is coupled to the support member. The mandrel includes a second fluid passage operably coupled to the first fluid passage, an interior portion, and an exterior portion. The interior portion of the mandrel is drillable. The tubular member is coupled to the mandrel.  
25 The shoe is coupled to the tubular member. The shoe includes a third fluid passage operably coupled to the second fluid passage, an interior portion, and an exterior portion. The interior portion of the shoe is drillable. Preferably, the interior portion of the mandrel includes a tubular member and a load bearing member. Preferably, the load bearing member comprises a drillable body.  
30 Preferably, the interior portion of the shoe includes a tubular member, and a load bearing member. Preferably, the load bearing member comprises a drillable body. Preferably, the exterior portion of the mandrel comprises an expansion cone.

WO 01/04535

PCT/US00/18635

Preferably, the expansion cone is fabricated from materials selected from the group consisting of tool steel, titanium, and ceramic. Preferably, the expansion cone has a surface hardness ranging from about 58 to 62 Rockwell C. Preferably at least a portion of the apparatus is drillable.

5        A wellhead has also been described that includes an outer casing and a plurality of substantially concentric and overlapping inner casings coupled to the outer casing. Each inner casing is supported by contact pressure between an outer surface of the inner casing and an inner surface of the outer casing. In a preferred embodiment, the outer casing has a yield strength ranging from about 40,000 to  
10 135,000 psi. In a preferred embodiment, the outer casing has a burst strength ranging from about 5,000 to 20,000 psi. In a preferred embodiment, the contact pressure between the inner casings and the outer casing ranges from about 500 to 10,000 psi. In a preferred embodiment, one or more of the inner casings include one or more sealing members that contact with an inner surface of the outer  
15 casing. In a preferred embodiment, the sealing members are selected from the group consisting of lead, rubber, Teflon, epoxy, and plastic. In a preferred embodiment, a Christmas tree is coupled to the outer casing. In a preferred embodiment, a drilling spool is coupled to the outer casing. In a preferred embodiment, at least one of the inner casings is a production casing.

20        A wellhead has also been described that includes an outer casing at least partially positioned within a wellbore and a plurality of substantially concentric inner casings coupled to the interior surface of the outer casing by the process of expanding one or more of the inner casings into contact with at least a portion of the interior surface of the outer casing. In a preferred embodiment, the inner  
25 casings are expanded by extruding the inner casings off of a mandrel. In a preferred embodiment, the inner casings are expanded by the process of placing the inner casing and a mandrel within the wellbore; and pressurizing an interior portion of the inner casing. In a preferred embodiment, during the pressurizing, the interior portion of the inner casing is fluidically isolated from an exterior portion  
30 of the inner casing. In a preferred embodiment, the interior portion of the inner casing is pressurized at pressures ranging from about 500 to 9,000 psi. In a preferred embodiment, one or more seals are positioned in the interface between

WO 01/04535

PCT/US00/18635

the inner casings and the outer casing. In a preferred embodiment, the inner casings are supported by their contact with the outer casing.

A method of forming a wellhead has also been described that includes drilling a wellbore. An outer casing is positioned at least partially within an upper  
5 portion of the wellbore. A first tubular member is positioned within the outer casing. At least a portion of the first tubular member is expanded into contact with an interior surface of the outer casing. A second tubular member is positioned within the outer casing and the first tubular member. At least a portion of the second tubular member is expanded into contact with an interior portion of  
10 the outer casing. In a preferred embodiment, at least a portion of the interior of the first tubular member is pressurized. In a preferred embodiment, at least a portion of the interior of the second tubular member is pressurized. In a preferred embodiment, at least a portion of the interiors of the first and second tubular members are pressurized. In a preferred embodiment, the pressurizing  
15 of the portion of the interior region of the first tubular member is provided at operating pressures ranging from about 500 to 9,000 psi. In a preferred embodiment, the pressurizing of the portion of the interior region of the second tubular member is provided at operating pressures ranging from about 500 to 9,000 psi. In a preferred embodiment, the pressurizing of the portion of the  
20 interior region of the first and second tubular members is provided at operating pressures ranging from about 500 to 9,000 psi. In a preferred embodiment, the pressurizing of the portion of the interior region of the first tubular member is provided at reduced operating pressures during a latter portion of the expansion. In a preferred embodiment, the pressurizing of the portion of the interior region  
25 of the second tubular member is provided at reduced operating pressures during a latter portion of the expansion. In a preferred embodiment, the pressurizing of the portion of the interior region of the first and second tubular members is provided at reduced operating pressures during a latter portion of the expansions. In a preferred embodiment, the contact between the first tubular member and the  
30 outer casing is sealed. In a preferred embodiment, the contact between the second tubular member and the outer casing is sealed. In a preferred embodiment, the contact between the first and second tubular members and the outer casing is

WO 01/04535

PCT/US00/18635

sealed. In a preferred embodiment, the expanded first tubular member is supported using the contact with the outer casing. In a preferred embodiment, the expanded second tubular member is supported using the contact with the outer casing. In a preferred embodiment, the expanded first and second tubular

5 members are supported using their contacts with the outer casing. In a preferred embodiment, the first and second tubular members are extruded off of a mandrel. In a preferred embodiment, the surface of the mandrel is lubricated. In a preferred embodiment, shock is absorbed. In a preferred embodiment, the mandrel is expanded in a radial direction. In a preferred embodiment, the first and

10 second tubular members are positioned in an overlapping relationship. In a preferred embodiment, an interior region of the first tubular member is fluidically isolated from an exterior region of the first tubular member. In a preferred embodiment, an interior region of the second tubular member is fluidically isolated from an exterior region of the second tubular member. In a preferred

15 embodiment, the interior region of the first tubular member is fluidically isolated from the region exterior to the first tubular member by injecting one or more plugs into the interior of the first tubular member. In a preferred embodiment, the interior region of the second tubular member is fluidically isolated from the region exterior to the second tubular member by injecting one or more plugs into the

20 interior of the second tubular member. In a preferred embodiment, the pressurizing of the portion of the interior region of the first tubular member is provided by injecting a fluidic material at operating pressures and flow rates ranging from about 500 to 9,000 psi and 40 to 3,000 gallons/minute. In a preferred embodiment, the pressurizing of the portion of the interior region of the second

25 tubular member is provided by injecting a fluidic material at operating pressures and flow rates ranging from about 500 to 9,000 psi and 40 to 3,000 gallons/minute. In a preferred embodiment, fluidic material is injected beyond the mandrel. In a preferred embodiment, a region of the tubular members beyond the mandrel is pressurized. In a preferred embodiment, the region of the tubular members

30 beyond the mandrel is pressurized to pressures ranging from about 500 to 9,000 psi. In a preferred embodiment, the first tubular member comprises a production casing. In a preferred embodiment, the contact between the first tubular member

WO 01/04535

PCT/US00/18635

and the outer casing is sealed. In a preferred embodiment, the contact between the second tubular member and the outer casing is sealed. In a preferred embodiment, the expanded first tubular member is supported using the outer casing. In a preferred embodiment, the expanded second tubular member is supported using the outer casing. In a preferred embodiment, the integrity of the seal in the contact between the first tubular member and the outer casing is tested.

In a preferred embodiment, the integrity of the seal in the contact between the second tubular member and the outer casing is tested. In a preferred embodiment, the mandrel is caught upon the completion of the extruding. In a preferred embodiment, the mandrel is drilled out. In a preferred embodiment, the mandrel is supported with coiled tubing. In a preferred embodiment, the mandrel is coupled to a drillable shoe.

An apparatus has also been described that includes an outer tubular member, and a plurality of substantially concentric and overlapping inner tubular members coupled to the outer tubular member. Each inner tubular member is supported by contact pressure between an outer surface of the inner casing and an inner surface of the outer inner tubular member. In a preferred embodiment, the outer tubular member has a yield strength ranging from about 40,000 to 135,000 psi. In a preferred embodiment, the outer tubular member has a burst strength ranging from about 5,000 to 20,000 psi. In a preferred embodiment, the contact pressure between the inner tubular members and the outer tubular member ranges from about 500 to 10,000 psi. In a preferred embodiment, one or more of the inner tubular members include one or more sealing members that contact with an inner surface of the outer tubular member. In a preferred embodiment, the sealing members are selected from the group consisting of rubber, lead, plastic, and epoxy.

An apparatus has also been described that includes an outer tubular member, and a plurality of substantially concentric inner tubular members coupled to the interior surface of the outer tubular member by the process of expanding one or more of the inner tubular members into contact with at least a portion of the interior surface of the outer tubular member. In a preferred embodiment, the inner tubular members are expanded by extruding the inner tubular members off

WO 01/04535

PCT/US00/18635

of a mandrel. In a preferred embodiment, the inner tubular members are expanded by the process of: placing the inner tubular members and a mandrel within the outer tubular member; and pressurizing an interior portion of the inner casing. In a preferred embodiment, during the pressurizing, the interior portion  
5 of the inner tubular member is fluidically isolated from an exterior portion of the inner tubular member. In a preferred embodiment, the interior portion of the inner tubular member is pressurized at pressures ranging from about 500 to 9,000 psi. In a preferred embodiment, the apparatus further includes one or more seals positioned in the interface between the inner tubular members and the outer  
10 tubular member. In a preferred embodiment, the inner tubular members are supported by their contact with the outer tubular member.

A wellbore casing has also been described that includes a first tubular member, and a second tubular member coupled to the first tubular member in an overlapping relationship. The inner diameter of the first tubular member is  
15 substantially equal to the inner diameter of the second tubular member. In a preferred embodiment, the first tubular member includes a first thin wall section, wherein the second tubular member includes a second thin wall section, and wherein the first thin wall section is coupled to the second thin wall section. In a preferred embodiment, first and second thin wall sections are deformed. In a  
20 preferred embodiment, the first tubular member includes a first compressible member coupled to the first thin wall section, and wherein the second tubular member includes a second compressible member coupled to the second thin wall section. In a preferred embodiment, the first thin wall section and the first compressible member are coupled to the second thin wall section and the second  
25 compressible member. In a preferred embodiment, the first and second thin wall sections and the first and second compressible members are deformed.

A wellbore casing has also been described that includes a tubular member including at least one thin wall section and a thick wall section, and  
a compressible annular member coupled to each thin wall section. In a preferred  
30 embodiment, the compressible annular member is fabricated from materials selected from the group consisting of rubber, plastic, metal and epoxy. In a preferred embodiment, the wall thickness of the thin wall section ranges from

WO 01/04535

PCT/US00/18635

about 50 to 100 % of the wall thickness of the thick wall section. In a preferred embodiment, the length of the thin wall section ranges from about 120 to 2400 inches. In a preferred embodiment, the compressible annular member is positioned along the thin wall section. In a preferred embodiment, the  
5 compressible annular member is positioned along the thin and thick wall sections. In a preferred embodiment, the tubular member is fabricated from materials selected from the group consisting of oilfield country tubular goods, stainless steel, low alloy steel, carbon steel, automotive grade steel, plastics, fiberglass, high strength and/or deformable materials. In a preferred embodiment, the wellbore  
10 casing includes a first thin wall at a first end of the casing, and a second thin wall at a second end of the casing.

A method of creating a casing in a borehole located in a subterranean formation has also been described that includes supporting a tubular liner and a mandrel in the borehole using a support member, injecting fluidic material into the  
15 borehole, pressurizing an interior region of the mandrel, displacing a portion of the mandrel relative to the support member, and radially expanding the tubular liner. In a preferred embodiment, the injecting includes injecting hardenable fluidic sealing material into an annular region located between the borehole and the exterior of the tubular liner, and injecting non hardenable fluidic material into an  
20 interior region of the mandrel. In a preferred embodiment, the method further includes fluidically isolating the annular region from the interior region before injecting the non hardenable fluidic material into the interior region of the mandrel. In a preferred embodiment, the injecting of the hardenable fluidic sealing material is provided at operating pressures and flow rates ranging from  
25 about 0 to 5,000 psi and 0 to 1,500 gallons/min. In a preferred embodiment, the injecting of the non hardenable fluidic material is provided at operating pressures and flow rates ranging from about 500 to 9,000 psi and 40 to 3,000 gallons/min. In a preferred embodiment, the injecting of the non hardenable fluidic material is provided at reduced operating pressures and flow rates during an end portion of  
30 the radial expansion. In a preferred embodiment, the fluidic material is injected into one or more pressure chambers. In a preferred embodiment, the one or more pressure chambers are pressurized. In a preferred embodiment, the pressure

WO 01/04535

PCT/US00/18635

chambers are pressurized to pressures ranging from about 500 to 9,000 psi. In a preferred embodiment, the method further includes fluidically isolating an interior region of the mandrel from an exterior region of the mandrel. In a preferred embodiment, the interior region of the mandrel is isolated from the region exterior to the mandrel by inserting one or more plugs into the injected fluidic material.

5 In a preferred embodiment, the method further includes curing at least a portion of the fluidic material, and removing at least a portion of the cured fluidic material located within the tubular liner. In a preferred embodiment, the method further includes overlapping the tubular liner with an existing wellbore casing. In a preferred embodiment, the method further includes sealing the overlap between the tubular liner and the existing wellbore casing. In a preferred embodiment, the method further includes supporting the extruded tubular liner using the overlap with the existing wellbore casing. In a preferred embodiment, the method further includes testing the integrity of the seal in the overlap between the tubular liner and the existing wellbore casing. In a preferred embodiment, the method further includes removing at least a portion of the hardenable fluidic sealing material within the tubular liner before curing. In a preferred embodiment, the method further includes lubricating the surface of the mandrel. In a preferred embodiment, the method further includes absorbing shock. In a preferred embodiment, the method further includes catching the mandrel upon the completion of the extruding. In a preferred embodiment, the method further includes drilling out the mandrel. In a preferred embodiment, the method further includes supporting the mandrel with coiled tubing. In a preferred embodiment, the mandrel reciprocates. In a preferred embodiment, the mandrel is displaced in a first direction during the pressurization of the interior region of the mandrel, and the mandrel is displaced in a second direction during a de-pressurization of the interior region of the mandrel. In a preferred embodiment, the tubular liner is maintained in a substantially stationary position during the pressurization of the interior region of the mandrel. In a preferred embodiment, the tubular liner is supported by the mandrel during a de-pressurization of the interior region of the mandrel.

10  
15  
20  
25  
30



WO 01/04535

PCT/US00/18635

A wellbore casing has also been described that includes a first tubular member having a first inside diameter, and a second tubular member having a second inside diameter substantially equal to the first inside diameter coupled to the first tubular member in an overlapping relationship. The first and second tubular members are coupled by the process of deforming a portion of the second tubular member into contact with a portion of the first tubular member. In a preferred embodiment, the second tubular member is deformed by the process of placing the first and second tubular members in an overlapping relationship, radially expanding at least a portion of the first tubular member, and radially expanding the second tubular member. In a preferred embodiment, the second tubular member is radially expanded by the process of supporting the second tubular member and a mandrel within the wellbore using a support member, injecting a fluidic material into the wellbore, pressurizing an interior region of the mandrel, and displacing a portion of the mandrel relative to the support member. In a preferred embodiment, the injecting includes injecting hardenable fluidic sealing material into an annular region located between the borehole and the exterior of the second liner, and injecting non hardenable fluidic material into an interior region of the mandrel. In a preferred embodiment, the wellbore casing further includes fluidically isolating the annular region from the interior region of the mandrel before injecting the non hardenable fluidic material into the interior region of the mandrel. In a preferred embodiment, the injecting of the hardenable fluidic sealing material is provided at operating pressures and flow rates ranging from about 0 to 5,000 psi and 0 to 1,500 gallons/min. In a preferred embodiment, the injecting of the non hardenable fluidic material is provided at operating pressures and flow rates ranging from about 500 to 9,000 psi and 40 to 3,000 gallons/min. In a preferred embodiment, the injecting of the non hardenable fluidic material is provided at reduced operating pressures and flow rates during an end portion of the radial expansion. In a preferred embodiment, the fluidic material is injected into one or more pressure chambers. In a preferred embodiment, one or more pressure chambers are pressurized. In a preferred embodiment, the pressure chambers are pressurized to pressures ranging from about 500 to 9,000 psi. In a preferred embodiment, the wellbore casing further

WO 01/04535

PCT/US00/18635

includes fluidically isolating an interior region of the mandrel from an exterior region of the mandrel. In a preferred embodiment, the interior region of the mandrel is isolated from the region exterior to the mandrel by inserting one or more plugs into the injected fluidic material. In a preferred embodiment, the wellbore casing further includes curing at least a portion of the fluidic material, and removing at least a portion of the cured fluidic material located within the second tubular liner. In a preferred embodiment, the wellbore casing further includes sealing the overlap between the first and second tubular liners. In a preferred embodiment, the wellbore casing further includes supporting the second tubular liner using the overlap with the first tubular liner. In a preferred embodiment, the wellbore casing further includes testing the integrity of the seal in the overlap between the first and second tubular liners. In a preferred embodiment, the wellbore casing further includes removing at least a portion of the hardenable fluidic sealing material within the second tubular liner before curing. In a preferred embodiment, the wellbore casing further includes lubricating the surface of the mandrel. In a preferred embodiment, the wellbore casing further includes absorbing shock. In a preferred embodiment, the wellbore casing further includes catching the mandrel upon the completion of the radial expansion. In a preferred embodiment, the wellbore casing further includes drilling out the mandrel. In a preferred embodiment, the wellbore casing further include supporting the mandrel with coiled tubing. In a preferred embodiment, the mandrel reciprocates. In a preferred embodiment, the mandrel is displaced in a first direction during the pressurization of the interior region of the mandrel; and wherein the mandrel is displaced in a second direction during a depressurization of the interior region of the mandrel. In a preferred embodiment, the second tubular liner is maintained in a substantially stationary position during the pressurization of the interior region of the mandrel. In a preferred embodiment, the second tubular liner is supported by the mandrel during a depressurization of the interior region of the mandrel.

An apparatus for expanding a tubular member has also been described that includes a support member including a fluid passage, a mandrel movably coupled to the support member including an expansion cone, at least one pressure chamber

WO 01/04535

PCT/US00/18635

defined by and positioned between the support member and mandrel fluidly coupled to the first fluid passage, and one or more releasable supports coupled to the support member adapted to support the tubular member. In a preferred embodiment, the fluid passage includes a throat passage having a reduced inner diameter. In a preferred embodiment, the mandrel includes one or more annular pistons. In a preferred embodiment, the apparatus includes a plurality of pressure chambers. In a preferred embodiment, the pressure chambers are at least partially defined by annular pistons. In a preferred embodiment, the releasable supports are positioned below the mandrel. In a preferred embodiment, the releasable supports are positioned above the mandrel. In a preferred embodiment, the releasable supports comprise hydraulic slips. In a preferred embodiment, the releasable supports comprise mechanical slips. In a preferred embodiment, the releasable supports comprise drag blocks. In a preferred embodiment, the mandrel includes one or more annular pistons, and an expansion cone coupled to the annular pistons. In a preferred embodiment, one or more of the annular pistons include an expansion cone. In a preferred embodiment, the pressure chambers comprise annular pressure chambers.

An apparatus has also been described that includes one or more solid tubular members, each solid tubular member including one or more external seals, one or more slotted tubular members coupled to the solid tubular members, and a shoe coupled to one of the slotted tubular members. In a preferred embodiment, the apparatus further includes one or more intermediate solid tubular members coupled to and interleaved among the slotted tubular members, each intermediate solid tubular member including one or more external seals. In a preferred embodiment, the apparatus further includes one or more valve members. In a preferred embodiment, one or more of the intermediate solid tubular members include one or more valve members.

A method of joining a second tubular member to a first tubular member, the first tubular member having an inner diameter greater than an outer diameter of the second tubular member, has also been described that includes positioning a mandrel within an interior region of the second tubular member, pressurizing a portion of the interior region of the mandrel, displacing the mandrel relative to the

WO 01/04535

PCT/US00/18635

second tubular member, and extruding at least a portion of the second tubular member off of the mandrel into engagement with the first tubular member. In a preferred embodiment, the pressurizing of the portion of the interior region of the mandrel is provided at operating pressures ranging from about 500 to 9,000 psi.

5 In a preferred embodiment, the pressurizing of the portion of the interior region of the mandrel is provided at reduced operating pressures during a latter portion of the extruding. In a preferred embodiment, the method further includes sealing the interface between the first and second tubular members. In a preferred embodiment, the method further includes supporting the extruded second tubular

10 member using the interface with the first tubular member. In a preferred embodiment, the method further includes lubricating the surface of the mandrel. In a preferred embodiment, the method further includes absorbing shock. In a preferred embodiment, the method further includes positioning the first and second tubular members in an overlapping relationship. In a preferred

15 embodiment, the method further includes fluidically isolating an interior region of the mandrel an exterior region of the mandrel. In a preferred embodiment, the interior region of the mandrel is fluidically isolated from the region exterior to the mandrel by injecting one or more plugs into the interior of the mandrel. In a preferred embodiment, the pressurizing of the portion of the interior region of the

20 mandrel is provided by injecting a fluidic material at operating pressures and flow rates ranging from about 500 to 9,000 psi and 40 to 3,000 gallons/minute. In a preferred embodiment, the method further includes injecting fluidic material beyond the mandrel. In a preferred embodiment, one or more pressure chambers defined by the mandrel are pressurized. In a preferred embodiment, the pressure

25 chambers are pressurized to pressures ranging from about 500 to 9,000 psi. In a preferred embodiment, the first tubular member comprises an existing section of a wellbore. In a preferred embodiment, the method further includes sealing the interface between the first and second tubular members. In a preferred embodiment, the method further includes supporting the extruded second tubular

30 member using the first tubular member. In a preferred embodiment, the method further includes testing the integrity of the seal in the interface between the first tubular member and the second tubular member. In a preferred embodiment, the

WO 01/04535

PCT/US00/18635

method further includes catching the mandrel upon the completion of the extruding. In a preferred embodiment, the method further includes drilling out the mandrel. In a preferred embodiment, the method further include supporting the mandrel with coiled tubing. In a preferred embodiment, the method further  
5 includes coupling the mandrel to a drillable shoe. In a preferred embodiment, the mandrel is displaced in the longitudinal direction. In a preferred embodiment, the mandrel is displaced in a first direction during the pressurization and in a second direction during a de-pressurization.

An apparatus has also been described that includes one or more primary  
10 solid tubulars, each primary solid tubular including one or more external annular seals, n slotted tubulars coupled to the primary solid tubulars, n-1 intermediate solid tubulars coupled to and interleaved among the slotted tubulars, each intermediate solid tubular including one or more external annular seals, and a shoe coupled to one of the slotted tubulars.

15 A method of isolating a first subterranean zone from a second subterranean zone in a wellbore has also been described that includes positioning one or more primary solid tubulars within the wellbore, the primary solid tubulars traversing the first subterranean zone, positioning one or more slotted tubulars within the wellbore, the slotted tubulars traversing the second subterranean zone, fluidicly  
20 coupling the slotted tubulars and the solid tubulars, and preventing the passage of fluids from the first subterranean zone to the second subterranean zone within the wellbore external to the solid and slotted tubulars.

A method of extracting materials from a producing subterranean zone in a wellbore, at least a portion of the wellbore including a casing, has also been  
25 described that includes positioning one or more primary solid tubulars within the wellbore, fluidicly coupling the primary solid tubulars with the casing, positioning one or more slotted tubulars within the wellbore, the slotted tubulars traversing the producing subterranean zone, fluidicly coupling the slotted tubulars with the solid tubulars, fluidicly isolating the producing subterranean zone from at least  
30 one other subterranean zone within the wellbore, and fluidicly coupling at least one of the slotted tubulars from the producing subterranean zone. In a preferred

WO 01/04535

PCT/US00/18635

embodiment, the method further includes controllably fluidically decoupling at least one of the slotted tubulars from at least one other of the slotted tubulars.

A method of creating a casing in a borehole while also drilling the borehole also has been described that includes installing a tubular liner, a mandrel, and a drilling assembly in the borehole. A fluidic material is injected within the tubular liner, mandrel and drilling assembly. At least a portion of the tubular liner is radially expanded while the borehole is drilled using the drilling assembly. In a preferred embodiment, the injecting includes injecting the fluidic material within an expandable chamber. In a preferred embodiment, the injecting includes injecting hardenable fluidic sealing material into an annular region located between the borehole and the exterior of the tubular liner. In a preferred embodiment, the injecting of the hardenable fluidic sealing material is provided at operating pressures and flow rates ranging from about 0 to 5,000 psi and 0 to 1,500 gallons/min. In a preferred embodiment, the injecting of the fluidic material is provided at operating pressures and flow rates ranging from about 500 to 9,000 psi and 40 to 3,000 gallons/min. In a preferred embodiment, the injecting of the fluidic material is provided at reduced operating pressures and flow rates during an end portion of the radial expansion. In a preferred embodiment, the method further includes curing at least a portion of the fluidic material; and removing at least a portion of the cured fluidic material located within the tubular liner. In a preferred embodiment, the method further includes overlapping the tubular liner with an existing wellbore casing. In a preferred embodiment, the method further includes sealing the overlap between the tubular liner and the existing wellbore casing. In a preferred embodiment, the method further includes supporting the extruded tubular liner using the overlap with the existing wellbore casing. In a preferred embodiment, the method further includes testing the integrity of the seal in the overlap between the tubular liner and the existing wellbore casing. In a preferred embodiment, the method further includes lubricating the surface of the mandrel. In a preferred embodiment, the method further includes absorbing shock. In a preferred embodiment, the method further includes catching the mandrel upon the completion of the extruding. In a preferred embodiment, the method further includes expanding the mandrel in a radial direction. In a

WO 01/04535

PCT/US00/18635

preferred embodiment, the method further includes drilling out the mandrel. In a preferred embodiment, the method further includes supporting the mandrel with coiled tubing. In a preferred embodiment, the wall thickness of the tubular member is variable. In a preferred embodiment, the mandrel is coupled to a  
5 drillable shoe.

An apparatus has also been described that includes a support member, the support member including a first fluid passage; a mandrel coupled to the support member, the mandrel including: a second fluid passage; a tubular member coupled to the mandrel; and a shoe coupled to the tubular liner, the shoe including a third  
10 fluid passage; and a drilling assembly coupled to the shoe; wherein the first, second and third fluid passages and the drilling assembly are operably coupled. In a preferred embodiment, the support member further includes: a pressure relief passage; and a flow control valve coupled to the first fluid passage and the pressure relief passage. In a preferred embodiment, the support member further includes  
15 a shock absorber. In a preferred embodiment, the support member includes one or more sealing members adapted to prevent foreign material from entering an interior region of the tubular member. In a preferred embodiment, the support member includes one or more stabilizers. In a preferred embodiment, the mandrel is expandable. In a preferred embodiment, the tubular member is fabricated from  
20 materials selected from the group consisting of Oilfield Country Tubular Goods, automotive grade steel, plastic and chromium steel. In a preferred embodiment, the tubular member has inner and outer diameters ranging from about 0.75 to 47 inches and 1.05 to 48 inches, respectively. In a preferred embodiment, the tubular member has a plastic yield point ranging from about 40,000 to 135,000 psi. In a  
25 preferred embodiment, the tubular member includes one or more sealing members at an end portion. In a preferred embodiment, the tubular member includes one or more pressure relief holes at an end portion. In a preferred embodiment, the tubular member includes a catching member at an end portion for slowing down movement of the mandrel. In a preferred embodiment, the support member  
30 comprises coiled tubing. In a preferred embodiment, at least a portion of the mandrel and shoe are drillable. In a preferred embodiment, the wall thickness of the tubular member in an area adjacent to the mandrel is less than the wall

WO 01/04535

PCT/US00/18635

thickness of the tubular member in an area that is not adjacent to the mandrel. In a preferred embodiment, the apparatus further includes an expandable chamber. In a preferred embodiment, the expandable chamber is approximately cylindrical. In a preferred embodiment, the expandable chamber is approximately  
5 annular.

A method of forming an underground pipeline within an underground tunnel including at least a first tubular member and a second tubular member, the first tubular member having an inner diameter greater than an outer diameter of the second tubular member, has also been described that includes positioning the  
10 first tubular member within the tunnel; positioning the second tubular member within the tunnel in an overlapping relationship with the first tubular member; positioning a mandrel and a drilling assembly within an interior region of the second tubular member; injecting a fluidic material within the mandrel, drilling  
assembly and the second tubular member; extruding at least a portion of the  
15 second tubular member off of the mandrel into engagement with the first tubular member; and drilling the tunnel. In a preferred embodiment, the injecting of the fluidic material is provided at operating pressures ranging from about 500 to 9,000 psi. In a preferred embodiment, the injecting of the fluidic material is provided at reduced operating pressures during a latter portion of the extruding. In a  
20 preferred embodiment, the method further includes sealing the interface between the first and second tubular members. In a preferred embodiment, the method further includes supporting the extruded second tubular member using the interface with the first tubular member. In a preferred embodiment, the method further includes lubricating the surface of the mandrel. In a preferred  
25 embodiment, the method further includes absorbing shock. In a preferred embodiment, the method further includes expanding the mandrel in a radial direction. In a preferred embodiment, the method further includes sealing the interface between the first and second tubular members. In a preferred embodiment, the method further includes supporting the extruded second tubular  
30 member using the first tubular member. In a preferred embodiment, the method further includes testing the integrity of the seal in the interface between the first tubular member and the second tubular member. In a preferred embodiment, the



WO 01/04535

PCT/US00/18635

method further includes catching the mandrel upon the completion of the extruding. In a preferred embodiment, the method further includes drilling out the mandrel. In a preferred embodiment, the method further includes supporting the mandrel with coiled tubing. In a preferred embodiment, the method further includes coupling the mandrel to a drillable shoe. In a preferred embodiment, the fluidic material is injected into an expandable chamber. In a preferred embodiment, the expandable chamber is substantially cylindrical. In a preferred embodiment, the expandable chamber is substantially annular. An apparatus has also been described that includes a wellbore, the wellbore formed by the process of drilling the wellbore; and a tubular liner positioned within the wellbore, the tubular liner formed by the process of extruding the tubular liner off of a mandrel while drilling the wellbore. In a preferred embodiment, the tubular liner is formed by the process of: placing the tubular liner and mandrel within the wellbore; and pressurizing an interior portion of the tubular liner. In a preferred embodiment, the interior portion of the tubular liner is pressurized at pressures ranging from about 500 to 9,000 psi. In a preferred embodiment, the tubular liner is formed by the process of: placing the tubular liner and mandrel within the wellbore; and pressurizing an interior portion of the mandrel. In a preferred embodiment, the interior portion of the mandrel is pressurized at pressures ranging from about 500 to 9,000 psi. In a preferred embodiment, the apparatus further includes an annular body of a cured fluidic material coupled to the tubular liner. In a preferred embodiment, the annular body of a cured fluidic sealing material is formed by the process of: injecting a body of hardenable fluidic sealing material into an annular region external of the tubular liner. In a preferred embodiment, the tubular liner overlaps with an existing wellbore casing. In a preferred embodiment, the apparatus further includes a seal positioned in the overlap between the tubular liner and the existing wellbore casing. In a preferred embodiment, the tubular liner is supported by the overlap with the existing wellbore casing. In a preferred embodiment, the process of extruding the tubular liner includes the pressurizing of an expandable chamber. In a preferred embodiment, the expandable chamber is substantially cylindrical. In a preferred embodiment, the expandable chamber is substantially annular.

WO 01/04535

PCT/US00/18635

A method of forming a wellbore casing in a wellbore has also been described that includes drilling out the wellbore while forming the wellbore casing. In a preferred embodiment, the forming includes: expanding a tubular member in the radial direction. In a preferred embodiment, the expanding includes: displacing  
5 a mandrel relative to the tubular member. In a preferred embodiment, the displacing includes: expanding an expandable chamber. In a preferred embodiment, the expandable chamber comprises a cylindrical chamber. In a preferred embodiment, the expandable chamber comprises an annular chamber.

A method of expanding a tubular member has also been described that  
10 includes placing a mandrel within the tubular member, pressurizing an annular region within the tubular member, and displacing the mandrel with respect to the tubular member. In a preferred embodiment, the method further includes removing fluids within the tubular member that are displaced by the displacement of the mandrel. In a preferred embodiment, the removed fluids pass inside the  
15 annular region. In a preferred embodiment, the volume of the annular region increases. In a preferred embodiment, the method further includes sealing off the annular region. In a preferred embodiment, sealing off the annular region includes sealing a stationary member and sealing a non-stationary member. In a preferred embodiment, the method further includes conveying fluids in opposite directions.  
20 In a preferred embodiment, the method further includes conveying a pressurized fluid and a non-pressurized fluid in opposite directions. In a preferred embodiment, the pressurizing is provided at operating pressures ranging from about 0 to 9,000 psi. In a preferred embodiment, the pressurizing is provided at flow rates ranging from about 0 to 3,000 gallons/minute.

25 A method of coupling a tubular member to preexisting structure has also been described that includes positioning the tubular member in an overlapping relationship to the preexisting structure, placing a mandrel within the tubular member, pressurizing an annular region within the tubular member, and displacing the mandrel with respect to the tubular member. In a preferred  
30 embodiment, the method further includes removing fluids within the tubular member that are displaced by the displacement of the mandrel. In a preferred embodiment, the removed fluids pass inside the annular region. In a preferred

WO 01/04535

PCT/US00/18635

embodiment, the volume of the annular region increases. In a preferred embodiment, the method further includes sealing off the annular region. In a preferred embodiment, sealing off the annular region includes sealing a stationary member and sealing a non-stationary member. In a preferred embodiment, the method further includes conveying fluids in opposite directions. In a preferred embodiment, the method further includes conveying a pressurized fluid and a non-pressurized fluid in opposite directions. In a preferred embodiment, the pressurizing is provided at operating pressures ranging from about 0 to 9,000 psi. In a preferred embodiment, the pressurizing is provided at flow rates ranging from about 0 to 3,000 gallons/minute.

A method of repairing a defect in a preexisting structure using a tubular member has also been described that includes positioning the tubular member in an overlapping relationship to the defect in the preexisting structure; placing a mandrel within the tubular member, pressurizing an annular region within the tubular member, and displacing the mandrel with respect to the tubular member. In a preferred embodiment, the method further includes removing fluids within the tubular member that are displaced by the displacement of the mandrel. In a preferred embodiment, the removed fluids pass inside the annular region. In a preferred embodiment, the volume of the annular region increases. In a preferred embodiment, the method further includes sealing off the annular region. In a preferred embodiment, sealing off the annular region includes sealing a stationary member and sealing a non-stationary member. In a preferred embodiment, the method further includes conveying fluids in opposite directions. In a preferred embodiment, the method further includes conveying a pressurized fluid and a non-pressurized fluid in opposite directions. In a preferred embodiment, the pressurizing is provided at operating pressures ranging from about 0 to 9,000 psi. In a preferred embodiment, the pressurizing is provided at flow rates ranging from about 0 to 3,000 gallons/minute. In a preferred embodiment, the method further includes sealing the interface between the preexisting structure and the tubular member at ends of the tubular member.

An apparatus for radially expanding a tubular member has also been described that includes a first tubular member, a second tubular member

WO 01/04535

PCT/US00/18635

positioned within the first tubular member, a third tubular member movably coupled to and positioned within the second tubular member, a first annular sealing member for sealing an interface between the first and second tubular members, a second annular sealing member for sealing an interface between the second and third tubular members, and a mandrel positioned within the first tubular member and coupled to an end of the third tubular member. In a preferred embodiment, the apparatus further includes an annular chamber defined by the first tubular member, the second tubular member, the third tubular member, the first annular sealing member, the second annular sealing member, and the mandrel. In a preferred embodiment, the apparatus further includes an annular passage defined by the second tubular member and the third tubular member. In a preferred embodiment, the apparatus further includes a fluid passage contained within the third tubular member and the mandrel. In a preferred embodiment, the apparatus further includes one or more sealing members coupled to an exterior surface of the first tubular member. In a preferred embodiment, the apparatus further includes an annular chamber defined by the first tubular member, the second tubular member, the third tubular member, the first annular sealing member, the second annular sealing member, and the mandrel, and annular passage defined by the second tubular member and the third tubular member. In a preferred embodiment, the annular chamber and the annular passage are fluidically coupled. In a preferred embodiment, the apparatus further includes one or more slips coupled to the exterior surface of the first tubular member. In a preferred embodiment, the mandrel includes a conical surface. In a preferred embodiment, the angle of attack of the conical surface ranges from about 10 to 30 degrees. In a preferred embodiment, the conical surface has a surface hardness ranging from about 58 to 62 Rockwell C.

An apparatus has also been described that includes a tubular member, a piston adapted to expand the diameter of the tubular member positioned within the tubular member, the piston including a passage for conveying fluids out of the tubular member, and an annular chamber defined by the piston and tubular member. In a preferred embodiment, the piston includes a conical surface. In a preferred embodiment, the angle of attack of the conical surface ranges from about

WO 01/04535

PCT/US00/18635

10 to 30 degrees. In a preferred embodiment, the conical surface has a surface hardness ranging from about 58 to 62 Rockwell C. In a preferred embodiment, the tubular member includes one or more sealing members coupled to the exterior surface of the tubular member.

5       A wellbore casing has also been described that includes a first tubular member and a second tubular member coupled to the first tubular member. The second tubular member is coupled to the first tubular member by the process of positioning the second tubular member in an overlapping relationship to the first tubular member, placing a mandrel within the second tubular member,  
10       pressurizing an annular region within the second tubular member, and displacing the mandrel with respect to the second tubular member. In a preferred embodiment, the wellbore casing further includes removing fluids within the second tubular member that are displaced by the displacement of the mandrel. In a preferred embodiment, the removed fluids pass inside the annular region. In a  
15       preferred embodiment, the volume of the annular region increases. In a preferred embodiment, the wellbore casing further includes sealing off the annular region. In a preferred embodiment, sealing off the annular region includes sealing a stationary member and sealing a non-stationary member. In a preferred embodiment, the wellbore casing further including conveying fluids in opposite  
20       directions. In a preferred embodiment, the wellbore casing further includes conveying a pressurized fluid and a non-pressurized fluid in opposite directions. In a preferred embodiment, the pressurizing is provided at operating pressures ranging from about 0 to 9,000 psi. In a preferred embodiment, the pressurizing is provided at flow rates ranging from about 0 to 3,000 gallons/minute.

25       An apparatus has also been described that includes a preexisting structure and a tubular member coupled to the preexisting structure. The tubular member is coupled to the preexisting structure by the process of: positioning the tubular member in an overlapping relationship to the preexisting structure, placing a mandrel within the tubular member, pressurizing an annular region within the  
30       tubular member, and displacing the mandrel with respect to the tubular member. In a preferred embodiment, the apparatus further includes removing fluids within the tubular member that are displaced by the displacement of the mandrel. In a

WO 01/04535

PCT/US00/18635

preferred embodiment, the removed fluids pass inside the annular region. In a preferred embodiment, the volume of the annular region increases. In a preferred embodiment, the apparatus further includes sealing off the annular region. In a preferred embodiment, sealing off the annular region includes sealing a stationary member and sealing a non-stationary member. In a preferred embodiment, the apparatus further includes conveying fluids in opposite directions. In a preferred embodiment, the apparatus further includes conveying a pressurized fluid and a non-pressurized fluid in opposite directions. In a preferred embodiment, the pressurizing is provided at operating pressures ranging from about 0 to 9,000 psi.

10 In a preferred embodiment, the pressurizing is provided at flow rates ranging from about 0 to 3,000 gallons/minute.

An apparatus has also been described that includes a preexisting structure having a defective portion and a tubular member coupled to the defective portion of the preexisting structure. The tubular member is coupled to the defective portion of the preexisting structure by the process of: positioning the tubular member in an overlapping relationship to the defect in the preexisting structure, placing a mandrel within the tubular member, pressurizing an annular region within the tubular member, and displacing the mandrel with respect to the tubular member. In a preferred embodiment, the apparatus further includes removing fluids within the tubular member that are displaced by the displacement of the mandrel. In a preferred embodiment, the removed fluids pass inside the annular region. In a preferred embodiment, the volume of the annular region increases. In a preferred embodiment, the apparatus further includes sealing off the annular region. In a preferred embodiment, sealing off the annular region includes sealing a stationary member and sealing a non-stationary member. In a preferred embodiment, the apparatus further includes conveying fluids in opposite directions. In a preferred embodiment, the apparatus further includes conveying a pressurized fluid and a non-pressurized fluid in opposite directions. In a preferred embodiment, the pressurizing is provided at operating pressures ranging from about 0 to 9,000 psi. In a preferred embodiment, the pressurizing is provided at flow rates ranging from about 0 to 3,000 gallons/minute. In a preferred

WO 01/04535

PCT/US00/18635

embodiment, the apparatus further includes sealing the interface between the preexisting structure and the tubular member at ends of the tubular member.

A method of expanding a tubular member has also been described that includes placing a mandrel within the tubular member, pressurizing a region  
5 within the tubular member, and displacing the mandrel with respect to the tubular member. In a preferred embodiment, the pressurizing is provided at operating pressures ranging from about 0 to 9,000 psi. In a preferred embodiment, the pressurizing is provided at flow rates ranging from about 0 to 3,000 gallons/minute. In a preferred embodiment, the tubular member is expanded  
10 beginning at an upper portion of the tubular member.

A method of coupling a tubular member to preexisting structure has also been described that includes positioning the tubular member in an overlapping relationship to the preexisting structure, placing a mandrel within the tubular member, pressurizing an interior region within the tubular member, and  
15 displacing the mandrel with respect to the tubular member. In a preferred embodiment, the pressurizing is provided at operating pressures ranging from about 0 to 9,000 psi. In a preferred embodiment, the pressurizing is provided at flow rates ranging from about 0 to 3,000 gallons/minute. In a preferred embodiment, the tubular member is expanded beginning at an upper portion of the  
20 tubular member.

A method of repairing a defect in a preexisting structure using a tubular member has also been described that includes positioning the tubular member in an overlapping relationship to the defect in the preexisting structure, placing a mandrel within the tubular member, pressurizing an interior region within the  
25 tubular member, and displacing the mandrel with respect to the tubular member. In a preferred embodiment, the pressurizing is provided at operating pressures ranging from about 0 to 9,000 psi. In a preferred embodiment, the pressurizing is provided at flow rates ranging from about 0 to 3,000 gallons/minute. In a preferred embodiment, the tubular member is expanded beginning at an upper  
30 portion of the tubular member. In a preferred embodiment, the method further includes sealing the interface between the preexisting structure and the tubular member at both ends of the tubular member.

WO 01/04535

PCT/US00/18635

An apparatus for radially expanding a tubular member has also been described that includes a first tubular member, a second tubular member coupled to the first tubular member, a third tubular member coupled to the second tubular member, and a mandrel positioned within the second tubular member and coupled to an end portion of the third tubular member. In a preferred embodiment, the mandrel includes a fluid passage having an inlet adapted to receive fluid stop member. In a preferred embodiment, the apparatus further includes one or more slips coupled to the exterior surface of the third tubular member. In a preferred embodiment, the mandrel includes a conical surface. In a preferred embodiment, the angle of attack of the conical surface ranges from about 10 to 30 degrees. In a preferred embodiment, the conical surface has a surface hardness ranging from about 58 to 62 Rockwell C. In a preferred embodiment, the average inside diameter of the second tubular member is greater than the average inside diameter of the third tubular member.

An apparatus has also been described that includes a tubular member, a piston adapted to expand the diameter of the tubular member positioned within the tubular member, the piston including a passage for conveying fluids out of the tubular member. In a preferred embodiment, the piston includes a conical surface. In a preferred embodiment, the angle of attack of the conical surface ranges from about 10 to 30 degrees. In a preferred embodiment, the conical surface has a surface hardness ranging from about 58 to 62 Rockwell C. In a preferred embodiment, the tubular member includes one or more sealing members coupled to the exterior surface of the tubular member.

A wellbore casing has also been described that includes a first tubular member and a second tubular member coupled to the first tubular member. The second tubular member is coupled to the first tubular member by the process of: positioning the second tubular member in an overlapping relationship to the first tubular member, placing a mandrel within the second tubular member, pressurizing an interior region within the second tubular member, and displacing the mandrel with respect to the second tubular member. In a preferred embodiment, the pressurizing is provided at operating pressures ranging from



WO 01/04535

PCT/US00/18635

about 0 to 9,000 psi. In a preferred embodiment, the pressurizing is provided at flow rates ranging from about 0 to 3,000 gallons/minute.

An apparatus has also been described that includes a preexisting structure and a tubular member coupled to the preexisting structure. The tubular member is coupled to the preexisting structure by the process of: positioning the tubular member in an overlapping relationship to the preexisting structure, placing a mandrel within the tubular member, pressurizing an interior region within the tubular member, and displacing the mandrel with respect to the tubular member. In a preferred embodiment, the pressurizing is provided at operating pressures ranging from about 0 to 9,000 psi. In a preferred embodiment, the pressurizing is provided at flow rates ranging from about 0 to 3,000 gallons/minute.

An apparatus has also been described that includes a preexisting structure having a defective portion and a tubular member coupled to the defective portion of the preexisting structure. The tubular member is coupled to the defective portion of the preexisting structure by the process of: positioning the tubular member in an overlapping relationship to the defect in the preexisting structure, placing a mandrel within the tubular member, pressurizing an interior region within the tubular member, and displacing the mandrel with respect to the tubular member. In a preferred embodiment, the pressurizing is provided at operating pressures ranging from about 0 to 9,000 psi. In a preferred embodiment, the pressurizing is provided at flow rates ranging from about 0 to 3,000 gallons/minute. In a preferred embodiment, the apparatus further includes sealing the interface between the preexisting structure and the tubular member at both ends of the tubular member.

An apparatus also has been described that includes a first tubular member, a second tubular member, and a threaded connection for coupling the first tubular member to the second tubular member. The threaded connection includes one or more sealing members for sealing the interface between the first and second tubular members. In a preferred embodiment, the threaded connection comprises a pin and box threaded connection. In a preferred embodiment, the sealing members are positioned adjacent to an end portion of the threaded connection. In a preferred embodiment, one of the sealing members is positioned adjacent to an

WO 01/04535

PCT/US00/18635

end portion of the threaded connection; and wherein another one of the sealing members is not positioned adjacent to an end portion of the threaded connection. In a preferred embodiment, a plurality of the sealing members are positioned adjacent to an end portion of the threaded connection.

5       An apparatus also has been described that includes a tubular assembly having a first tubular member, a second tubular member, and a threaded connection for coupling the first tubular member to the second tubular member. The threaded connection includes one or more sealing members for sealing the interface between the first and second tubular members. The tubular assembly is  
10       formed by the process of radially expanding the tubular assembly. In a preferred embodiment, the threaded connection comprises a pin and box threaded connection. In a preferred embodiment, the sealing members are positioned adjacent to an end portion of the threaded connection. In a preferred embodiment,  
15       one of the sealing members is positioned adjacent to an end portion of the threaded connection; and wherein another one of the sealing members is not positioned adjacent to an end portion of the threaded connection. In a preferred embodiment, a plurality of the sealing members are positioned adjacent to an end portion of the threaded connection.

20       An apparatus also has been described that includes a tubular member and a mandrel positioned within the tubular member including a conical surface have an angle of attack ranging from about 10 to 30 degrees. In a preferred embodiment, the tubular member includes a first tubular member, a second tubular member, and a threaded connection for coupling the first tubular member to the second tubular member. The threaded connection includes one or more  
25       sealing members for sealing the interface between the first and second tubular members. In a preferred embodiment, the threaded connection comprises a pin and box threaded connection. In a preferred embodiment, the sealing members are positioned adjacent to an end portion of the threaded connection. In a preferred embodiment, one of the sealing members is positioned adjacent to an end portion  
30       of the threaded connection; and wherein another one of the sealing members is not positioned adjacent to an end portion of the threaded connection. In a preferred

WO 01/04535

PCT/US00/18635

embodiment, a plurality of the sealing members are positioned adjacent to an end portion of the threaded connection.

An expansion cone for expanding a tubular member has also been described that includes a housing including a tapered first end and a second end, one or more  
5 grooves formed in the outer surface of the tapered first end, and one or more axial flow passages fluidically coupled to the circumferential grooves. In a preferred embodiment, the grooves comprise circumferential grooves. In a preferred embodiment, the grooves comprise spiral grooves. In a preferred embodiment, the grooves are concentrated around the axial midpoint of the tapered portion of the  
10 housing. In a preferred embodiment, the axial flow passages comprise axial grooves. In a preferred embodiment, the axial grooves are spaced apart by at least about 3 inches in the circumferential direction. In a preferred embodiment, the axial grooves extend from the tapered first end of the body to the grooves. In a preferred embodiment, the axial grooves extend from the second end of the body  
15 to the grooves. In a preferred embodiment, the axial grooves extend from the tapered first end of the body to the second end of the body. In a preferred embodiment, the flow passages are positioned within the housing of the expansion cone. In a preferred embodiment, the flow passages extend from the tapered first end of the body to the grooves. In a preferred embodiment, the flow passages  
20 extend from the tapered first end of the body to the second end of the body. In a preferred embodiment, the flow passages extend from the second end of the body to the grooves. In a preferred embodiment, one or more of the flow passages include inserts having restricted flow passages. In a preferred embodiment, one or more of the flow passages include filters. In a preferred embodiment, the cross  
25 sectional area of the grooves is greater than the cross sectional area of the axial flow passages. In a preferred embodiment, the cross-sectional area of the grooves ranges from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$ . In a preferred embodiment, the cross-sectional area of the axial flow passages ranges from about  $2 \times 10^{-4} \text{ in}^2$  to  $5 \times 10^{-2} \text{ in}^2$ . In a preferred embodiment, the angle of attack of the first tapered end of the body  
30 ranges from about 10 to 30 degrees. In a preferred embodiment, the grooves are concentrated in a trailing edge portion of the tapered first end. In a preferred embodiment, the angle of inclination of the axial flow passages relative to the

WO 01/04535

PCT/US00/18635

longitudinal axis of the expansion cone is greater than the angle of attack of the first tapered end. In a preferred embodiment, the grooves include a flow channel having a first radius of curvature, a first shoulder positioned on one side of the flow channel having a second radius of curvature, and a second shoulder positioned  
5 on the other side of the flow channel having a third radius of curvature. In a preferred embodiment, the first, second and third radii of curvature are substantially equal. In a preferred embodiment, the axial flow passages include a flow channel having a first radius of curvature, a first shoulder positioned on one side of the flow channel having a second radius of curvature, and a second shoulder  
10 positioned on the other side of the flow channel having a third radius of curvature. In a preferred embodiment, the first, second and third radii of curvature are substantially equal. In a preferred embodiment, the second radius of curvature is greater than the third radius of curvature.

A method of lubricating the interface between a tubular member and an  
15 expansion cone having a first tapered end and a second end during the radial expansion of the tubular member by the expansion cone, wherein the interface between the tubular member and the first tapered end of the expansion cone includes a leading edge portion and a trailing edge portion, has also been described that includes injecting a lubricating fluid into the trailing edge portion. In a  
20 preferred embodiment, the lubricating fluid has a viscosity ranging from about 1 to 10,000 centipoise. In a preferred embodiment, the injecting includes injecting lubricating fluid into the first tapered end of the expansion cone. In a preferred embodiment, the injecting includes injecting lubricating fluid into the area around the axial midpoint of the first tapered end of the expansion cone. In a preferred  
25 embodiment, the injecting includes injecting lubricating fluid into the second end of the expansion cone. In a preferred embodiment, the injecting includes injecting lubricating fluid into the tapered first end and the second end of the expansion cone. In a preferred embodiment, the injecting includes injecting lubricating fluid into the interior of the expansion cone. In a preferred embodiment, the injecting  
30 includes injecting lubricating fluid through the outer surface of the expansion cone. In a preferred embodiment, the injecting includes injecting the lubricating fluid into a plurality of discrete locations along the trailing edge portion. In a

WO 01/04535

PCT/US00/18635

preferred embodiment, the lubricating fluid comprises drilling mud. In a preferred embodiment, the lubricating fluid further includes TorqTrim III, EP Mudlib, and DrillN-Slid. In a preferred embodiment, the lubricating fluid comprises TorqTrim III, EP Mudlib, and DrillN-Slid.

- 5 A method of removing debris formed during the radial expansion of a tubular member by an expansion cone from the interface between the tubular member and the expansion cone, the expansion cone including a first tapered end and a second end, the interface between the tubular member and the first tapered end of the expansion cone includes a leading edge portion and a trailing edge
- 10 portion, also has been described that includes injecting a lubricating fluid into the interface between the tubular member and the expansion cone. In a preferred embodiment, the lubricating fluid has a viscosity ranging from about 1 to 10,000 centipoise. In a preferred embodiment, the injecting includes injecting lubricating fluid into the first tapered end of the expansion cone. In a preferred embodiment,
- 15 the injecting includes injecting lubricating fluid into the area around the axial midpoint of the first tapered end of the expansion cone. In a preferred embodiment, the injecting includes injecting lubricating fluid into the second end of the expansion cone. In a preferred embodiment, the injecting includes injecting lubricating fluid into the tapered first end and the second end of the expansion
- 20 cone. In a preferred embodiment, the injecting includes injecting lubricating fluid into the interior of the expansion cone. In a preferred embodiment, the injecting includes injecting lubricating fluid through the outer surface of the expansion cone. In a preferred embodiment, the lubricating fluid comprises drilling mud. In a preferred embodiment, the lubricating fluid further includes TorqTrim III, EP
- 25 Mudlib, and DrillN-Slid. In a preferred embodiment, the lubricating fluid comprises TorqTrim III, EP Mudlib, and DrillN-Slid.

- A tubular member has also been described that includes an annular member having a wall thickness that varies less than about 8 %, a hoop yield strength that varies less than about 10 %, imperfections of less than about 8 % of the wall
- 30 thickness, no failure for radial expansions of up to about 30 %, and no necking of the walls of the annular member for radial expansions of up to about 25%.

WO 01/04535

PCT/US00/18635

A wellbore casing has also been described that includes one or more tubular members. Each tubular member includes an annular member having a wall thickness that varies less than about 8 %, a hoop yield strength that varies less than about 10 %, imperfections of less than about 8 % of the wall thickness, no failure for radial expansions of up to about 30 %, and no necking of the walls of the annular member for radial expansions of up to about 25%.

A method of forming a wellbore casing also has been described that includes placing a tubular member and an expansion cone in a wellbore, and displacing the expansion cone relative to the tubular member. The tubular member includes an annular member having a wall thickness that varies less than about 8 %, a hoop yield strength that varies less than about 10 %, imperfections of less than about 8 % of the wall thickness, no failure for radial expansions of up to about 30 %, and no necking of the walls of the annular member for radial expansions of up to about 25%.

A method of selecting a group of tubular members for subsequent radial expansion also has been described that includes radially expanding the ends of a representative sample of the group of tubular members, measuring the amount of necking of the walls of the radially expanded ends of the tubular members, and if the radially expanded ends of the tubular members do not exhibit necking for radial expansions of up to about 25%, then accepting the group of tubular members.

A method of selecting a group of tubular members also has been described that includes radially expanding the ends of a representative sample of the group of tubular members until each of the tubular members fail, if the radially expanded ends of the tubular members do not fail for radial expansions of up to about 30%, then accepting the group of tubular members.

A method of inserting a tubular member into a wellbore also has been described that includes injecting a lubricating fluid into the wellbore, and inserting the tubular member into the wellbore. In a preferred embodiment, the lubricating fluid comprises BARO-LUB GOLD-SEAL™ brand drilling mud lubricant.

WO 01/04535

PCT/US00/18635

An expandable tubular member also has been described that includes a first tubular section having a first outer diameter, an intermediate tubular section coupled to the first tubular section having an intermediate outer diameter and a second tubular section having a second outer diameter coupled to the intermediate tubular section having a second outer diameter. The first and second outer diameters are greater than the intermediate outer diameter. In a preferred embodiment, the first tubular section includes a first threaded connection; and wherein the second tubular section includes a second threaded connection. In a preferred embodiment, the first and second threaded connections include pin and box threads. In a preferred embodiment, one of the first and second threaded connections include a sealing member. In a preferred embodiment, an outer surface of the first tubular section includes a first protective member and an outer surface of the second tubular section includes a second protective member. In a preferred embodiment, the first protective member comprises a thermoset polymer and the second protective member comprises a thermoset polymer. In a preferred embodiment, an outer surface of the intermediate tubular section includes a sealing member. In a preferred embodiment, the sealing member comprises a thermoset polymer. In a preferred embodiment, the expandable tubular section further includes a first transitional tubular section coupled between the first tubular section and the intermediate tubular section having a first angle of inclination and a second transitional tubular section coupled between the second tubular section and the intermediate tubular section having a second angle of inclination. The first and second angles of inclination preferably range from about 0 to 30 degrees. In a preferred embodiment, the wall thickness of the first tubular section is substantially equal to the wall thickness of the second tubular section. In a preferred embodiment, the wall thickness of the intermediate tubular section is less than the wall thicknesses of the first and second tubular sections. In a preferred embodiment, the wall thickness of the intermediate tubular section is less than the wall thicknesses of the first and second tubular sections.

A method of fabricating an expandable tubular member also has been described that includes providing a tubular member having a first end, a second end, and an intermediate portion and radially expanding the first end and the

WO 01/04535

PCT/US00/18635

- second end of the tubular member. In a preferred embodiment, prior to radially expanding, the first end and the second end of the tubular member are upset. In a preferred embodiment, the method further includes forming threaded connections on the first and second radially expanded ends of the tubular member.
- 5 In a preferred embodiment, the method further includes relieving stress in the first and second radially expanded ends of the tubular member. In a preferred embodiment, the method further includes applying a first protective member to the outside diameter of the first end of the tubular member and applying a second protective member to the outside diameter of the second end of the tubular
- 10 member. In a preferred embodiment, the method further includes applying a sealing member to the outside diameter of the intermediate portion of the tubular member. In a preferred embodiment, the relationship between the wall thicknesses of the expandable tubular member; the inside diameters of the expandable tubular member; the inside diameter  $D_{\text{wellbore}}$  of the wellbore casing that
- 15 the expandable tubular member will be inserted into; and the outside diameter  $D_{\text{cone}}$  of the expansion cone that will be used to radially expand the expandable tubular member within the wellbore casing is given by the following expression:

$$D_{\text{wellbore}} - 2 * t_1 \geq D_1 \geq \frac{1}{t_1} \left[ (t_1 - t_{\text{INT}}) * D_{\text{cone}} + t_{\text{INT}} * D_{\text{INT}} \right]$$

- where  $D_{\text{wellbore}}$  = inside diameter of the wellbore casing that the expandable
- 20 tubular member will be inserted into;
- $t_1$  = wall thickness of the first tubular section;
- $t_2$  = wall thickness of the second tubular section;
- $t_1$  =  $t_2$ ;
- $t_{\text{INT}}$  = wall thickness of the intermediate tubular section;
- 25  $D_1$  = inside diameter of the first tubular section;
- $D_2$  = inside diameter of the second tubular section;
- $D_1$  =  $D_2$ ;
- $D_{\text{INT}}$  = interior diameter of the intermediate tubular section; and



WO 01/04535

PCT/US00/18635

$D_{\text{cone}}$  = outside diameter of the expansion cone that will be used to radially expand the expandable tubular member within the wellbore casing.

An expansion cone for radially expanding a tubular member also has been described that includes a first outer surface having a first angle of attack and a second outer surface coupled to the first outer surface having a second angle of attack. The first angle of attack is greater than the second angle of attack. In a preferred embodiment, the expansion cone further includes a front end coupled to the first outer surface and a rear end coupled to the second outer surface. In a preferred embodiment, the first angle of attack ranges from about 8 to 20 degrees; and wherein the second angle of attack ranges from about 4 to 15 degrees. In a preferred embodiment, the expansion cone further includes one or more intermediate outer surfaces coupled between the first and second outer surfaces. In a preferred embodiment, the angle of attack of the intermediate outer surfaces continually decrease from the first outer surface to the second outer surface. In a preferred embodiment, the angle of attack of the intermediate outer surfaces decrease in steps from the first outer surface to the second outer surface. In a preferred embodiment, the angle of attack of the outer surfaces is defined by a parabolic equation. In a preferred embodiment, the angle of attack of the outer surfaces is defined by a parabolic equation.

An apparatus also has been described that includes a tubular member formed by the process of radially expanding an unexpanded tubular member into contact with an approximately cylindrical passage using an expansion cone. The unexpanded tubular member includes a first tubular section having a first outer diameter, an intermediate tubular section coupled to the first tubular section having an intermediate outer diameter and a second tubular section having a second outer diameter coupled to the intermediate tubular section having a second outer diameter. The first and second outer diameters are greater than the intermediate outer diameter. In a preferred embodiment, the first tubular section includes a first threaded connection; and wherein the second tubular section includes a second threaded connection. In a preferred embodiment, the first and second threaded connections include pin and box threads. In a preferred

WO 01/04535

PCT/US00/18635

embodiment, one of the first and second threaded connections include a sealing member. In a preferred embodiment, an outer surface of the first tubular section includes a first protective member and an outer surface of the second tubular section includes a second protective member. In a preferred embodiment, the first  
5 protective member comprises a thermoset polymer and the second protective member comprises a thermoset polymer. In a preferred embodiment, an outer surface of the intermediate tubular section includes a sealing member. In a preferred embodiment, the sealing member comprises a thermoset polymer. In a preferred embodiment, the expandable tubular section further includes a first  
10 transitional tubular section coupled between the first tubular section and the intermediate tubular section having a first angle of inclination and a second transitional tubular section coupled between the second tubular section and the intermediate tubular section having a second angle of inclination. The first and second angles of inclination preferably range from about 0 to 30 degrees. In a  
15 preferred embodiment, the wall thickness of the first tubular section is substantially equal to the wall thickness of the second tubular section. In a preferred embodiment, the wall thickness of the intermediate tubular section is less than the wall thicknesses of the first and second tubular sections. In a preferred embodiment, the wall thickness of the intermediate tubular section is  
20 less than the wall thicknesses of the first and second tubular sections. In a preferred embodiment, the expansion cone includes a first outer surface having a first angle of attack and a second outer surface coupled to the first outer surface having a second angle of attack. The first angle of attack is greater than the second angle of attack. In a preferred embodiment, the expansion cone further  
25 includes a front end coupled to the first outer surface and a rear end coupled to the second outer surface. In a preferred embodiment, the first angle of attack ranges from about 8 to 20 degrees; and wherein the second angle of attack ranges from about 4 to 15 degrees. In a preferred embodiment, the expansion cone further includes one or more intermediate outer surfaces coupled between the first and  
30 second outer surfaces. In a preferred embodiment, the angle of attack of the intermediate outer surfaces continually decrease from the first outer surface to the second outer surface. In a preferred embodiment, the angle of attack of the

WO 01/04535

PCT/US00/18635

intermediate outer surfaces decrease in steps from the first outer surface to the second outer surface. In a preferred embodiment, the angle of attack of the outer surfaces is defined by a parabolic equation. In a preferred embodiment, the angle of attack of the outer surfaces is defined by a parabolic equation.

5 A method of joining a first tubular member to a second tubular member also has been described that includes positioning at least a portion of the second tubular member within the first tubular member, radially expanding at least a portion of the second tubular member into contact with the first tubular member and radially expanding the first and second tubular members. The interior  
10 diameter of the radially expanded second tubular member is substantially equal to the interior diameter of the radially unexpanded portion of the first tubular member. In a preferred embodiment, radially expanding at least a portion of the second tubular member into contact with the first tubular member includes increasing the interior diameter of the second tubular member from about 2% to  
15 50%. In a preferred embodiment, radially expanding the first and second tubular members includes increasing the interior diameter of the first tubular member from about 0% to 40% and increasing the interior diameter of the second tubular member from about 2% to 50%. In a preferred embodiment, radially expanding the first and second tubular members includes plastically deforming the first and  
20 second tubular members. In a preferred embodiment, radially expanding the first and second tubular members includes pressurizing an interior portion of the first and second tubular members. In a preferred embodiment, radially expanding the first and second tubular members includes displacing an expansion mandrel relative to the first and second tubular members. In a preferred embodiment, the  
25 expansion mandrel is displaced in opposing directions.

A tubular member also has been described that includes a first tubular member and a second tubular member coupled to the first tubular member. The first and second tubular members are coupled by the process of positioning at least a portion of the second tubular member within the first tubular member, radially  
30 expanding at least a portion of the second tubular member into contact with the first tubular member and radially expanding the first and second tubular members. The interior diameter of the radially expanded second tubular member

WO 01/04535

PCT/US00/18635

is substantially equal to an interior diameter of the radially unexpanded portion of the first tubular member. In a preferred embodiment, radially expanding at least a portion of the second tubular member into contact with the first tubular member includes increasing the interior diameter of the second tubular member from about 2% to 50%. In a preferred embodiment, radially expanding the first and second tubular members includes increasing the interior diameter of the first tubular member from about 0% to 40% and increasing the interior diameter of the second tubular member from about 2% to 50%. In a preferred embodiment, radially expanding the first and second tubular members includes plastically deforming the first and second tubular members. In a preferred embodiment, radially expanding the first and second tubular members includes pressurizing an interior portion of the first and second tubular members. In a preferred embodiment, radially expanding the first and second tubular members includes displacing an expansion mandrel relative to the first and second tubular members. In a preferred embodiment, the expansion mandrel is displaced in opposing directions.

A tubular member also has been described that includes a first tubular member and a second tubular member. The first tubular member includes an upper portion having an upper wall thickness and a lower portion having a lower wall thickness. The second tubular member is coupled to the lower portion of the first tubular member. The interior diameters of the upper portion of the first tubular member and the second tubular member are substantially equal. In a preferred embodiment, the lower wall thickness is less than the upper wall thickness. In a preferred embodiment, the interface between the first and second tubular members has a tensile pullout rating greater than the tensile yield point for the first and second tubular members. In a preferred embodiment, the interface between the first and second tubular members has a torsional failure point greater than the torsional yield point for the first and second tubular members. In a preferred embodiment, the interface between the first and second tubular members has a pressure seal rating greater than the pressure seal rating for a conventional threaded connection including O-rings. In a preferred embodiment, the interface between the first and second tubular members has a

WO 01/04535

PCT/US00/18635

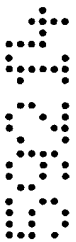
burst capacity greater than the burst capacity for the first and second tubular members.

An apparatus also has been described that includes a first tubular member, a second tubular member positioned in overlapping relation to the first tubular member, an expansion mandrel positioned within the first tubular member including one or more outer surfaces for radially expanding the first and second tubular members, a support member coupled to the expansion mandrel for supporting the expansion mandrel, a first fluid conduit positioned within the expansion mandrel and the support member, a packer sealingly coupled to the first tubular member and slidingly and sealingly coupled to the support member, a second fluid conduit coupled to the packer and a pump fluidly coupled to the second fluid conduit. In a preferred embodiment, the apparatus further includes an annular region defined by the packer, the expansion mandrel, the support member and the first tubular member, wherein the second fluid conduit is fluidly coupled to the annular region. In a preferred embodiment, the first fluid conduit is fluidly coupled to the interior of the second tubular member. In a preferred embodiment, the maximum outside diameter of the expansion mandrel is substantially equal to the inside diameter of the first tubular member. In a preferred embodiment, the expansion mandrel includes a pair of oppositely positioned outer conical surfaces. In a preferred embodiment, the apparatus further includes a slip joint for permitting the expansion mandrel to be displaced relative to the support member.

Although illustrative embodiments of the invention have been shown and described, a wide range of modification, changes and substitution is contemplated in the foregoing disclosure. In some instances, some features of the present invention may be employed without a corresponding use of the other features. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

- 320 -

Throughout this specification and the claims which follow, unless the context requires otherwise, the word "comprise", and variations such as "comprises" and "comprising", will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of  
5 integers or steps.



- 321 -

**The Claims Defining The Invention Are As Follows:**

1. An expandable tubular member for use in forming and/or repairing a wellbore casing, pipeline or structural support, including:
  - 5 a first tubular section having a first outer diameter and a first threaded connection;
  - a second tubular section having a second outer diameter and a second threaded connection; and
  - an intermediate tubular section between the first and second tubular sections and having an intermediate outer diameter;
  - 10 wherein the first and second outer diameters are greater than the intermediate outer diameter.
2. The expandable tubular member of claim 1, wherein the wall thicknesses of the first and second tubular sections are greater than the wall thickness of the intermediate tubular section.
  - 15
3. The expandable tubular member of claim 1 or 2, further comprising:
  - a first tubular transitional portion between the first tubular section and the intermediate tubular section; and
  - 20 a second tubular transitional portion between the second tubular section and the intermediate tubular section;
  - wherein the angles of inclination of the first and second tubular transitional portions relative to the intermediate tubular section are in the range of from about 0 to 30 degrees.
  - 25
4. The expandable tubular member of any one of claims 1 to 3, wherein the outside diameter of the intermediate tubular section is in the range of from about 75 percent to about 98 percent of the outside diameters of the first and second tubular sections.
- 30 5. The expandable tubular member of any one of claims 1 to 4, wherein the burst strength of the first and second tubular sections is substantially equal to the burst

- 322 -

strength of the intermediate tubular section.

6. The expandable tubular member of any one of claims 1 to 5, wherein the first threaded connection comprises an internally threaded connection; and wherein the second threaded connection comprises an externally threaded connection.
7. The expandable tubular member of any one of claims 1 to 6, wherein the ratio of the inside diameters of the first and second tubular sections to the interior diameter of the intermediate tubular section is in the range of from about 100 to 120 percent.
8. The expandable tubular member of any one of claims 1 to 7, wherein the relationship between the wall thicknesses  $t_1$ ,  $t_2$  and  $t_{INT}$  of the first tubular section, the second tubular section, and the intermediate tubular section, respectively, of the tubular member, the inside diameters  $D_1$ ,  $D_2$  and  $D_{INT}$  of the first tubular section, the second tubular section, and the intermediate tubular section, respectively, of the tubular member, and the inside diameter  $D_{wellbore}$  of a wellbore casing that the tubular member will be inserted into, and the outside diameter  $D_{cone}$  of an expansion cone that will be used to radially expand the tubular member within the wellbore casing is given by the following expression:

$$D_{wellbore} - 2 * t_1 \geq D_1 \geq 1/t_1[(t_1 - t_{INT}) * D_{cone} + t_{INT} * D_{INT}];$$

wherein  $t_1 = t_2$ ; and wherein  $D_1 = D_2$ .

9. An expandable tubular member according to claim 1 and substantially as herein described with reference to the accompanying drawings.
10. A method of fabricating an expandable tubular member for use in forming and/or repairing a wellbore casing, pipeline or structural support, comprising: providing a tubular member having a first end, a second end, and an intermediate portion;



- 323 -

radially expanding the first end and the second end of the tubular member whereby  
the outer diameters of the first end and the second end are greater than the  
outer diameter of the intermediate portion;  
forming a first threaded connection on the first end of the tubular member; and  
5 forming a second threaded connection on the second end of the tubular member.

11. The method of claim 10, further comprising:  
upsetting the first and second ends of the tubular member.

10 12. The method of claim 10 or 11, further comprising:  
stress relieving the radially expanded first and second ends of the tubular member.

13. The method of any one of claims 10 to 12 further comprising:  
applying a protective coating onto the radially expanded first and second ends of  
15 the tubular member.

14. The method of any one of claims 10 to 13, further comprising:  
applying a coating of a sealant onto the intermediate portion of the tubular member.

20 15. The method of any one of claims 10 to 14, wherein the wall thicknesses of the  
radially expanded first and second ends of the tubular member are greater than the  
wall thickness of the intermediate portion.

25 16. The method of any one of claims 10 to 15, further comprising:  
forming a first tubular transitional portion between the first end and the  
intermediate portion of the tubular member; and  
forming a second tubular transitional portion between the second end and the  
intermediate portion of the tubular member;  
wherein the angles of inclination of the first and second tubular transitional  
30 portions relative to the intermediate portion are in the range of from about 0  
to 30 degrees.

- 324 -

17. The method of any one of claims 10 to 16, wherein the outside diameter of the intermediate portion of the tubular member is in the range of from about 75 percent to about 98 percent of the outside diameters of the radially expanded first and second ends of the tubular member.
18. The method of any one of claims 10 to 17, wherein the burst strength of the radially expanded first and second ends of the tubular member is substantially equal to the burst strength of the intermediate portion of the tubular member.
19. The method of any one of claims 10 to 18, wherein the first threaded connection comprises an internally threaded connection; and wherein the second threaded connection comprises an externally threaded connection.
20. The method of any one of claims 10 to 19, wherein the ratio of the inside diameters of the first and second ends of the tubular member to the interior diameter of the intermediate portion of the tubular member is in the range of from about 100 to 120 percent.
21. The method of any one of claims 10 to 20, wherein the relationship between the wall thicknesses  $t_1$ ,  $t_2$ , and  $t_{INT}$  of the radially expanded first end, the radially expanded second end, and the intermediate portion, respectively, of the tubular member, the inside diameters  $D_1$ ,  $D_2$  and  $D_{INT}$  of the radially expanded first end, the radially expanded second end, and the intermediate portion, respectively, of the tubular member, and the inside diameter  $D_{wellbore}$  of a wellbore casing that the tubular member will be inserted into, and the outside diameter  $D_{cone}$  of an expansion cone that will be used to radially expand the tubular member within the wellbore casing is given by the following expression:

$$D_{wellbore} - 2 * t_1 \geq D_1 \geq 1/t_1 [(t_1 - t_{INT}) * D_{cone} + t_{INT} * D_{INT}];$$

- 325 -

wherein  $t_1 = t_2$ ; and wherein  $D_1 = D_2$ .

22. A method according to claim 10 and substantially as herein described with reference to the accompanying drawings.
- 5 23. An expandable tubular member when fabricated by a method according to any one of claims 10 to 22.
24. A wellbore casing, pipeline or structural support comprising a tubular member formed by the process of radially expanding an expandable tubular member
- 10 according to any one of claims 1 to 9 and 23 into contact with an approximately cylindrical passage using an expansion cone.

Dated this 9<sup>th</sup> day of July 2004

15 Shell Internationale Research Maatschappij B.V.

By Its Patent Attorneys

**DAVIES COLLISON CAVE**



WO 01/04535

PCT/US00/18635

1/83

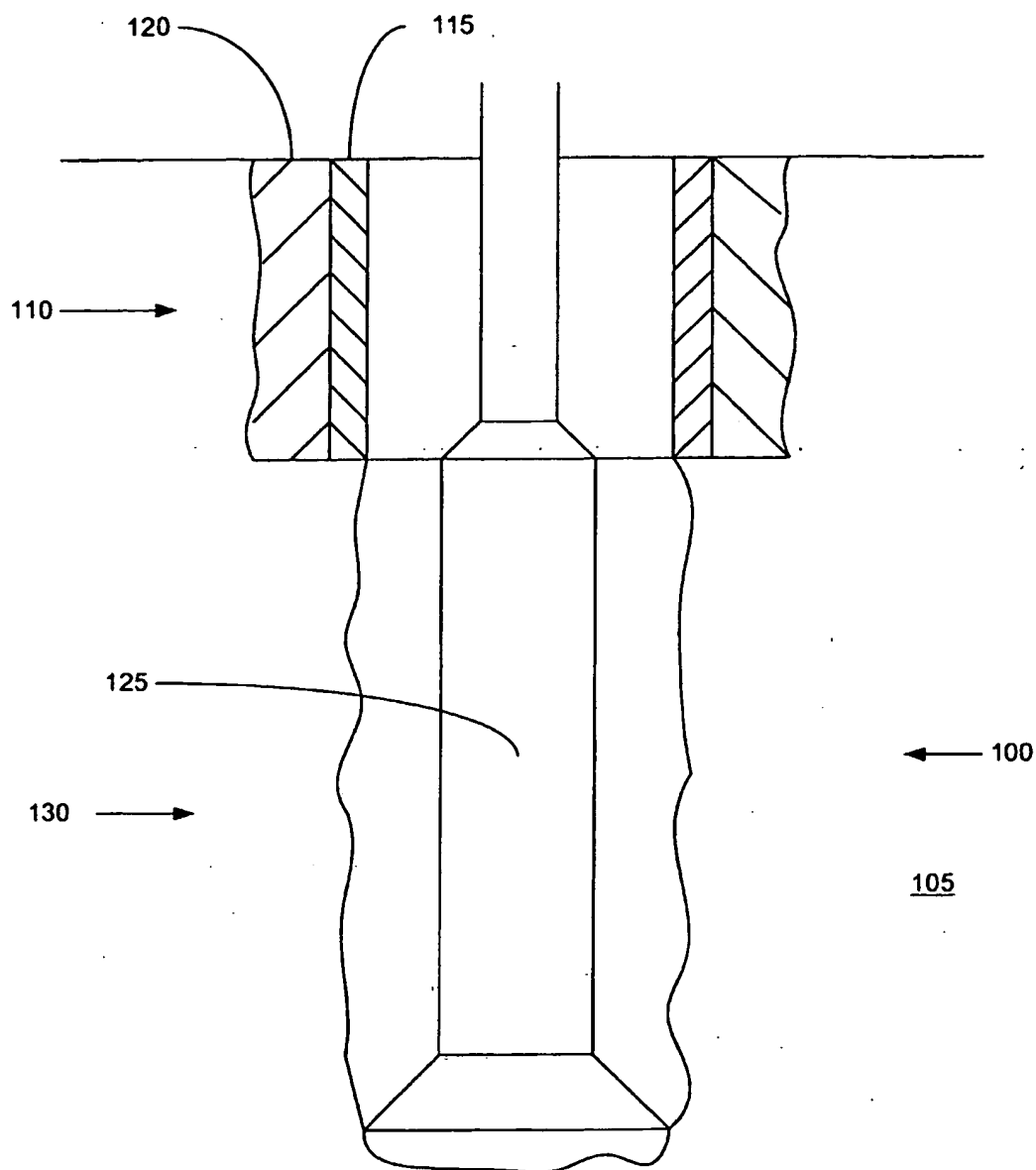


FIGURE 1

WO 01/04535

PCT/US00/18635

2/83

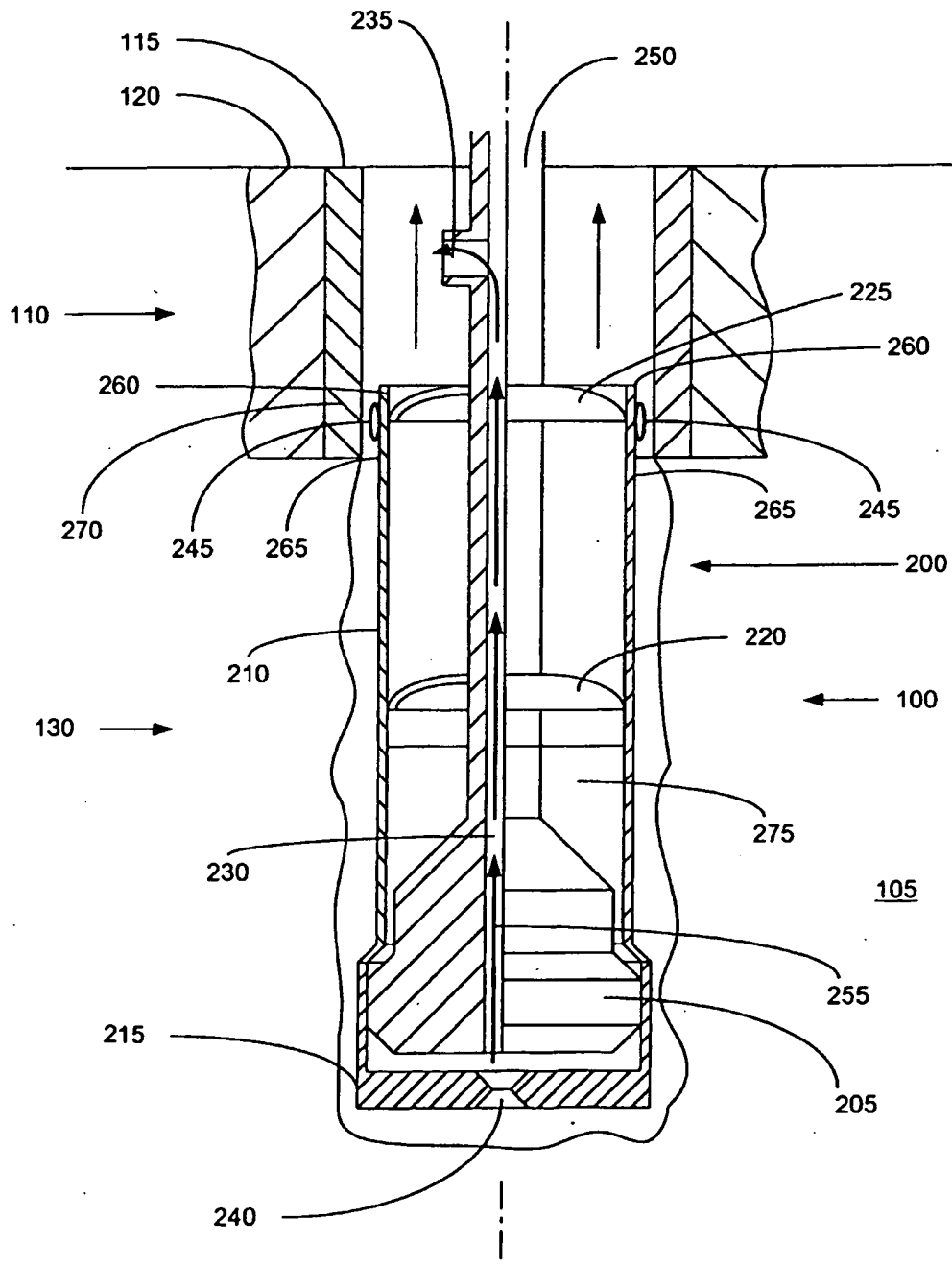


FIGURE 2

WO 01/04535

PCT/US00/18635

3/83

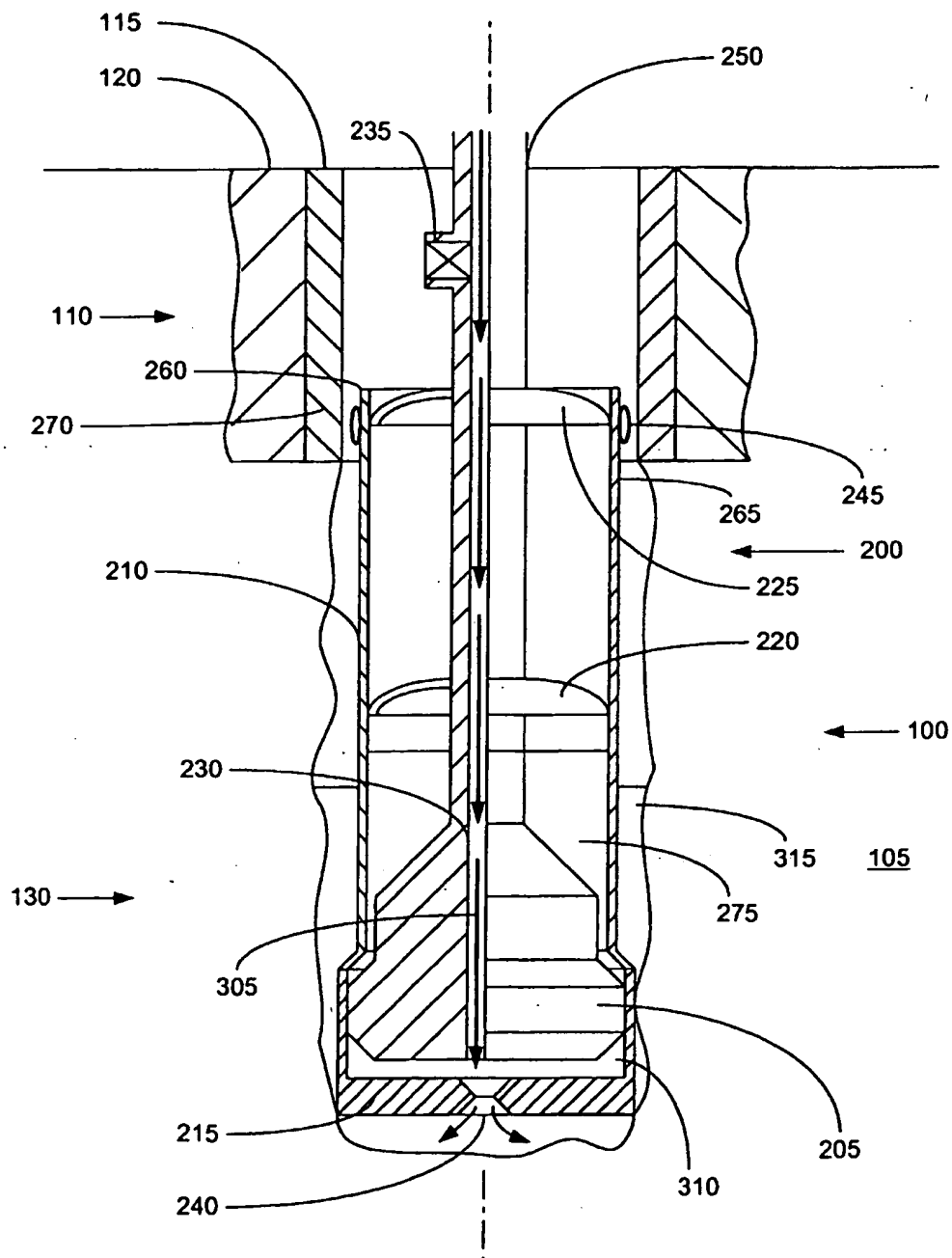


FIGURE 3

WO 01/04535

PCT/US00/18635

4/83

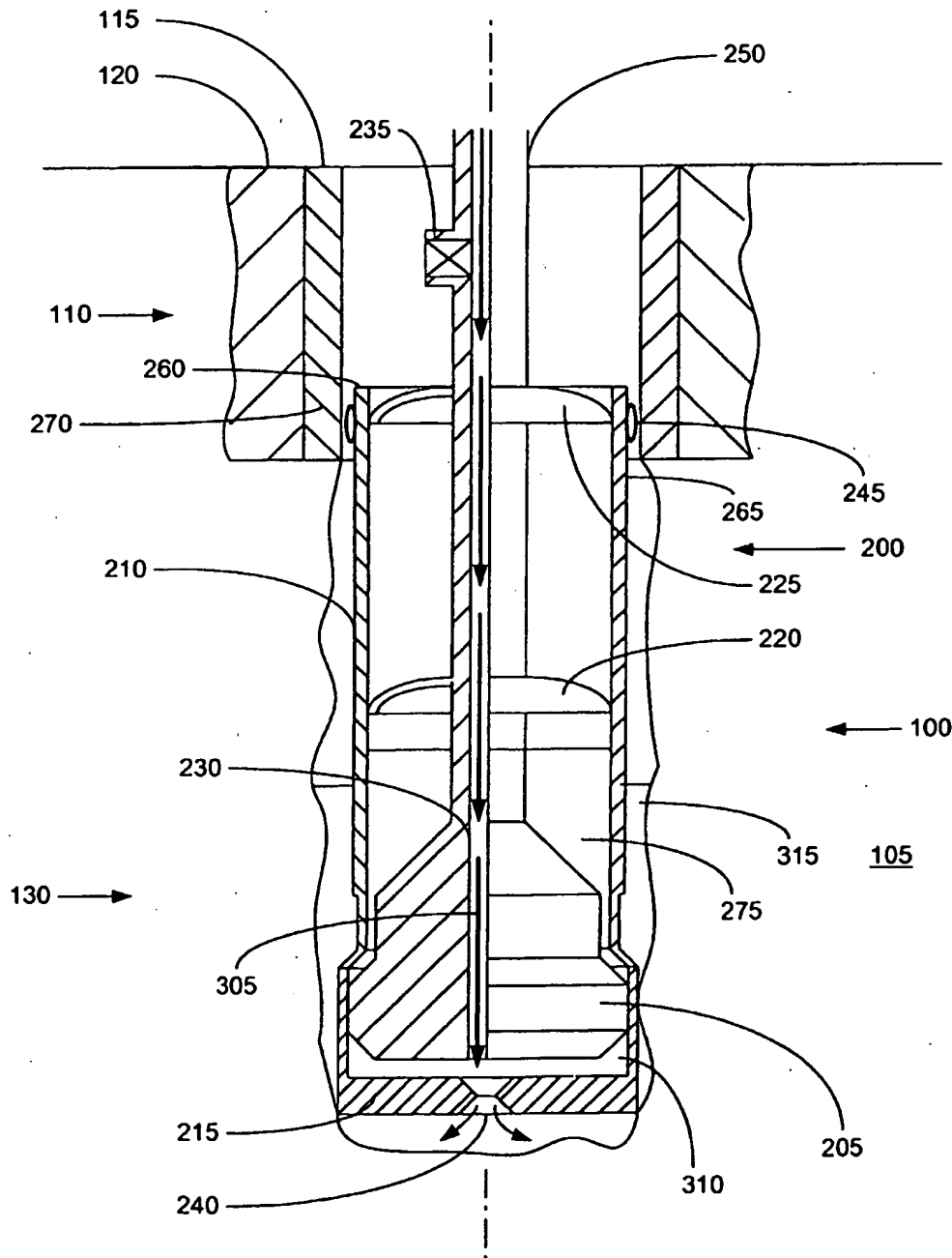


FIGURE 3a

WO 01/04535

PCT/US00/18635

5/83

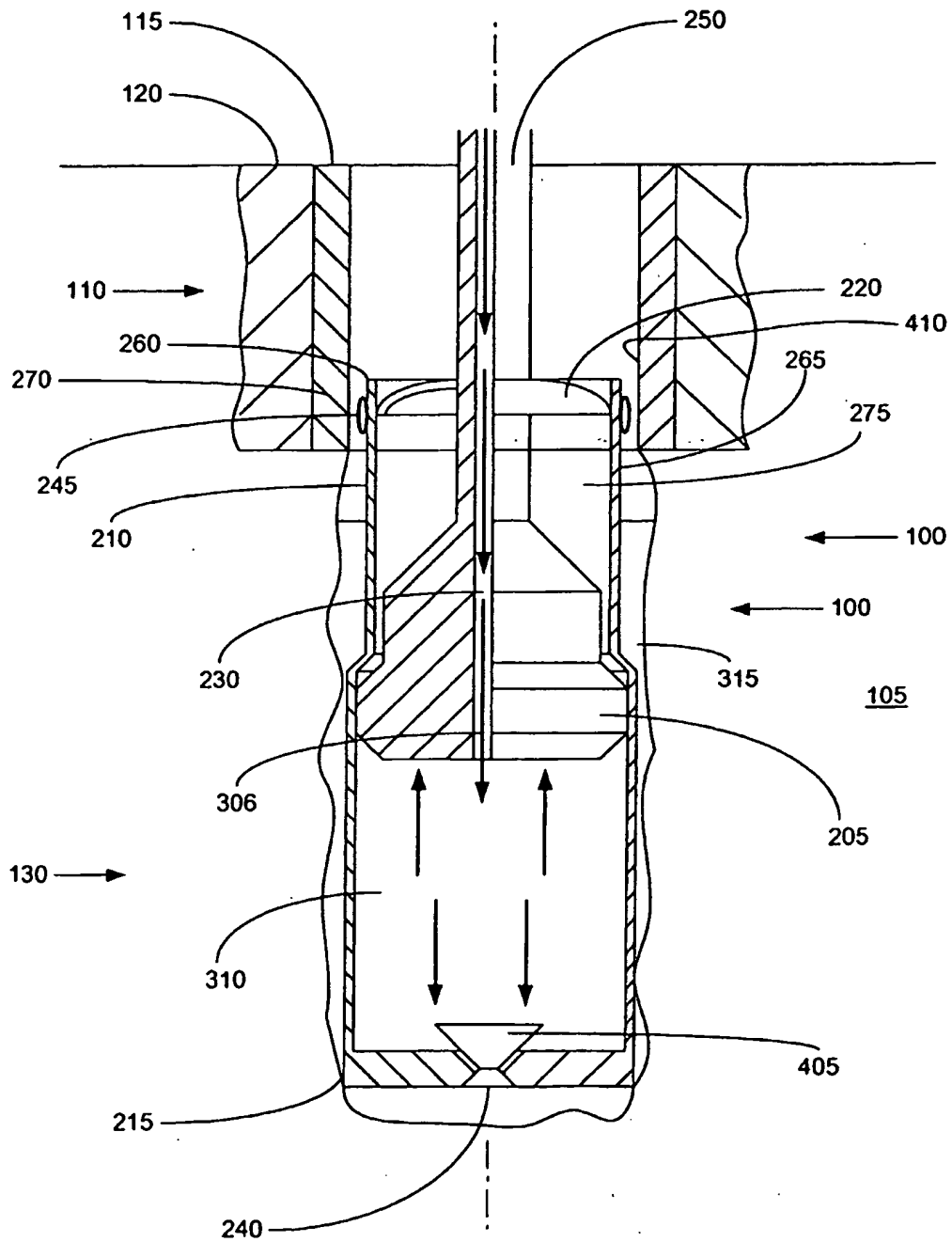


FIGURE 4



WO 01/04535

PCT/US00/18635

6/83

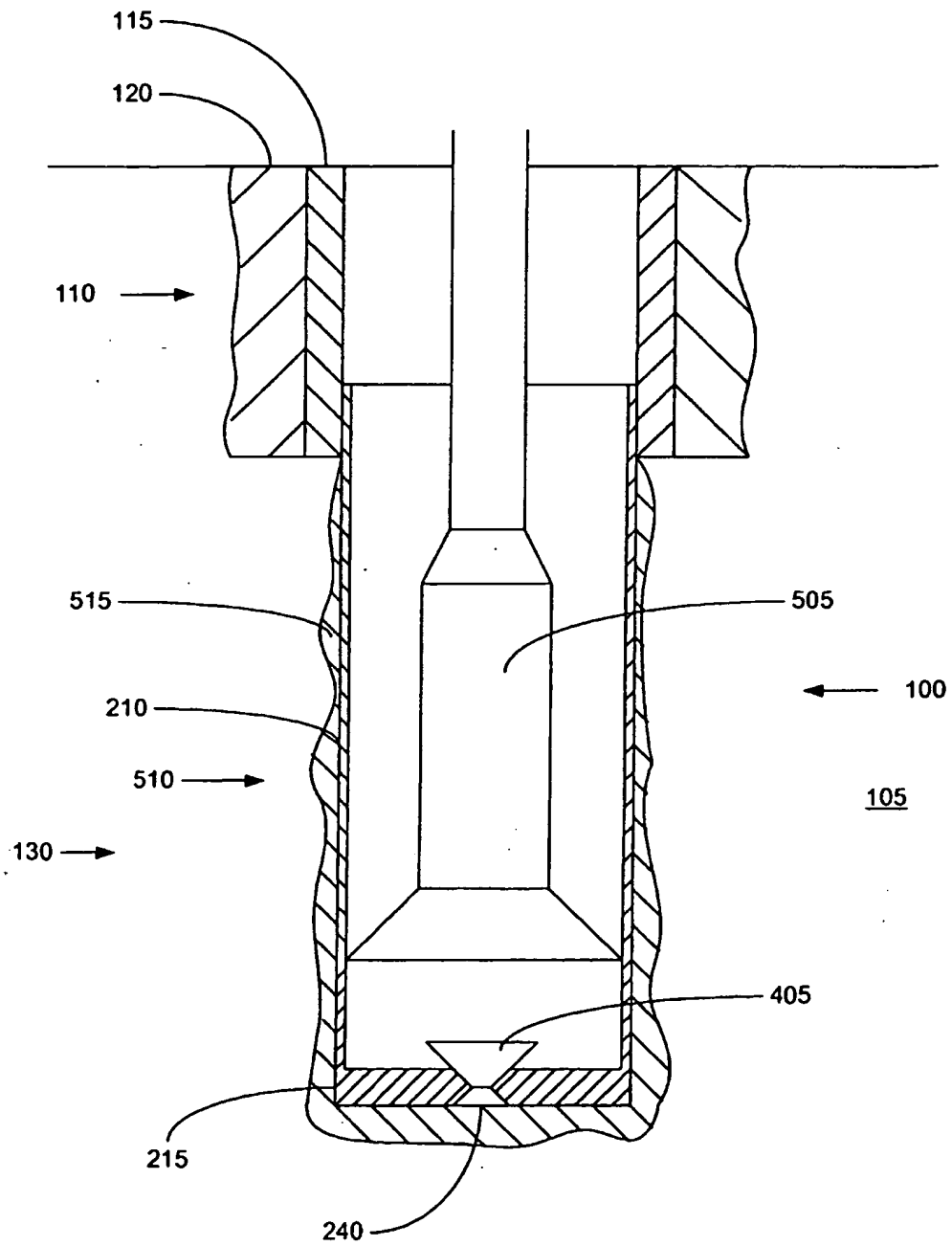


FIGURE 5

WO 01/04535

PCT/US00/18635

7/83

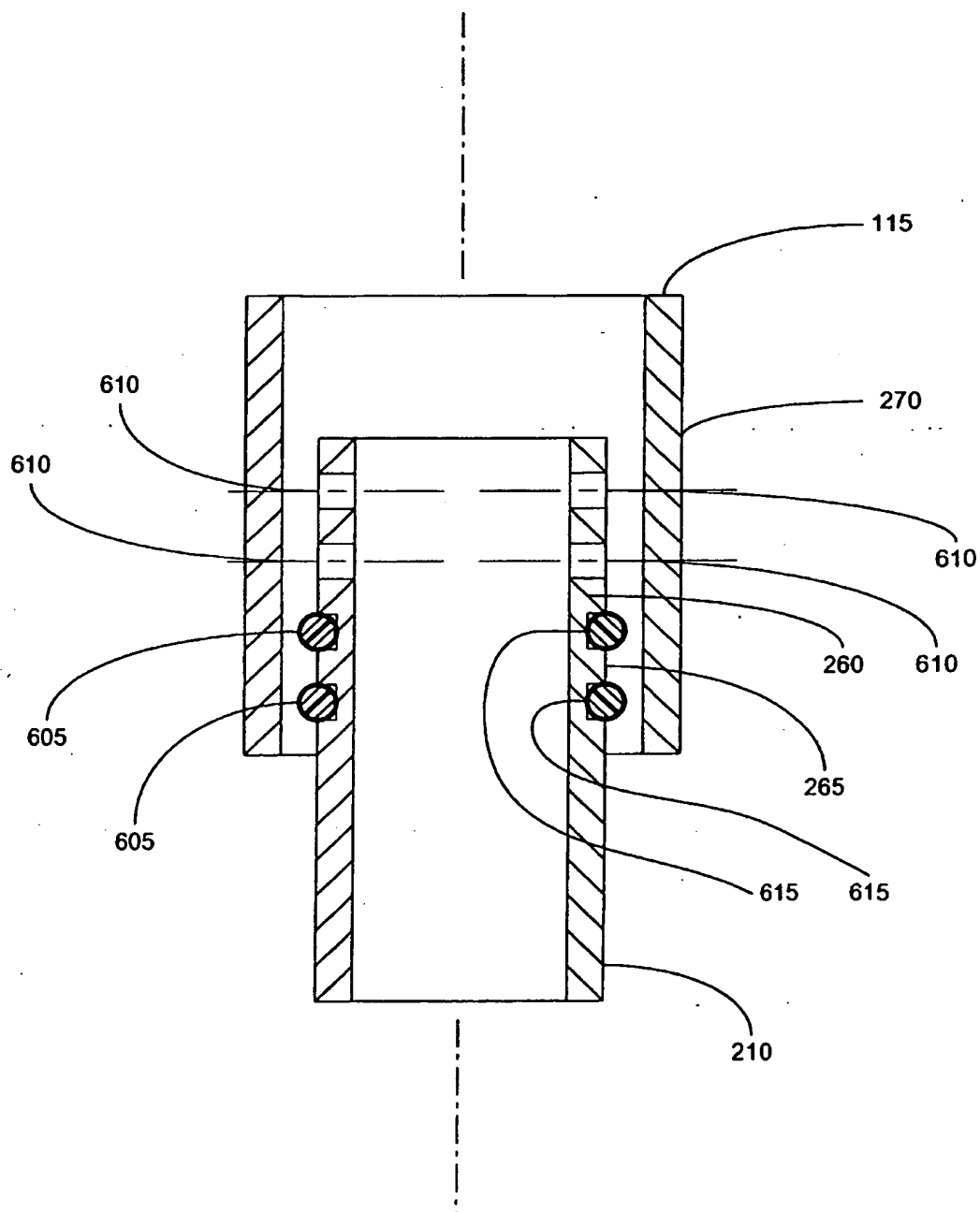


FIGURE 6

WO 01/04535

PCT/US00/18635

8/83

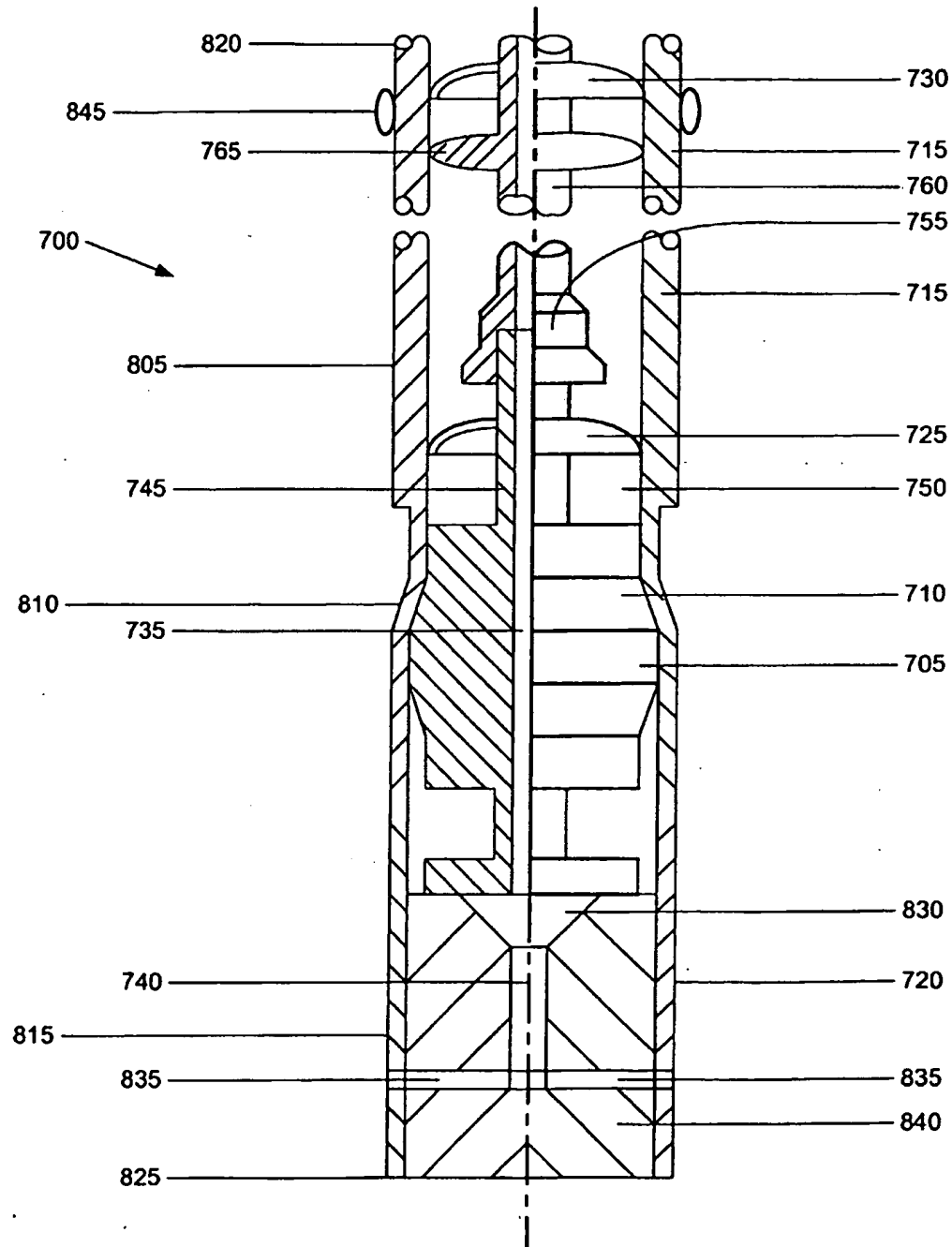


FIGURE 7

WO 01/04535

PCT/US00/18635

9/83

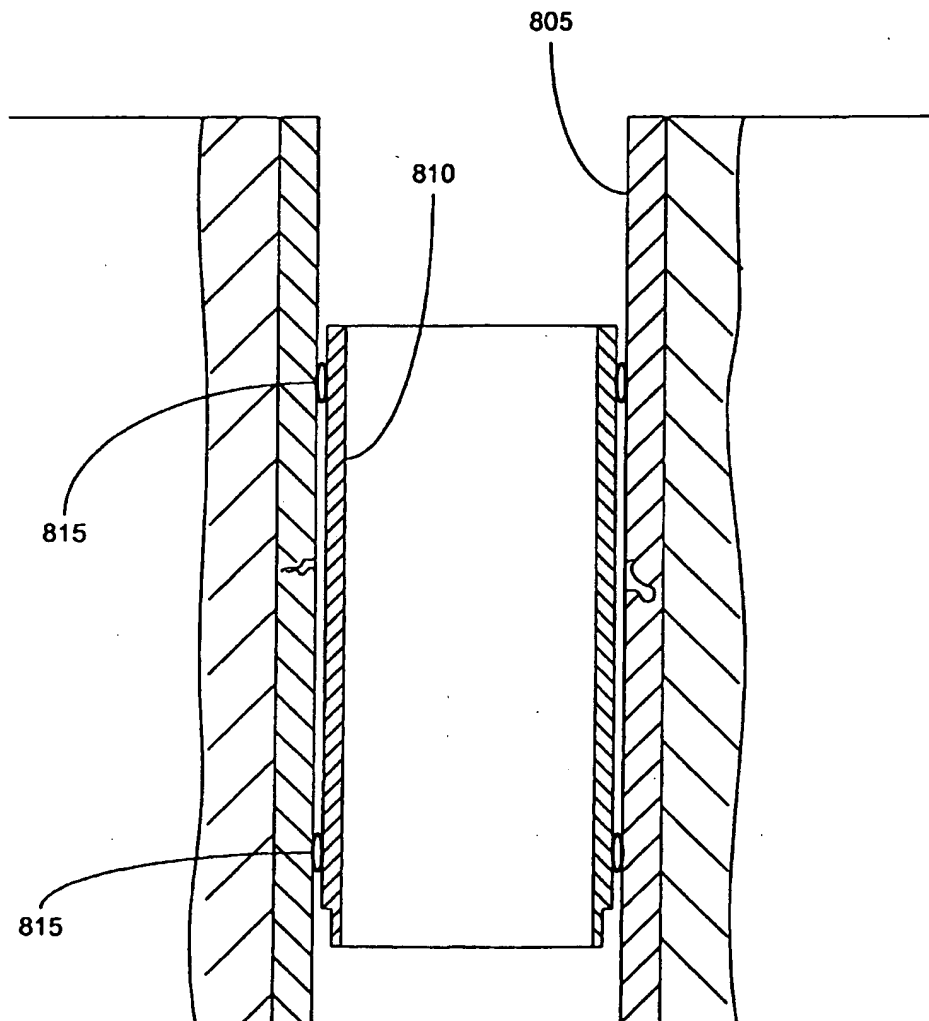


FIGURE 8

WO 01/04535

10/83

PCT/US00/18635

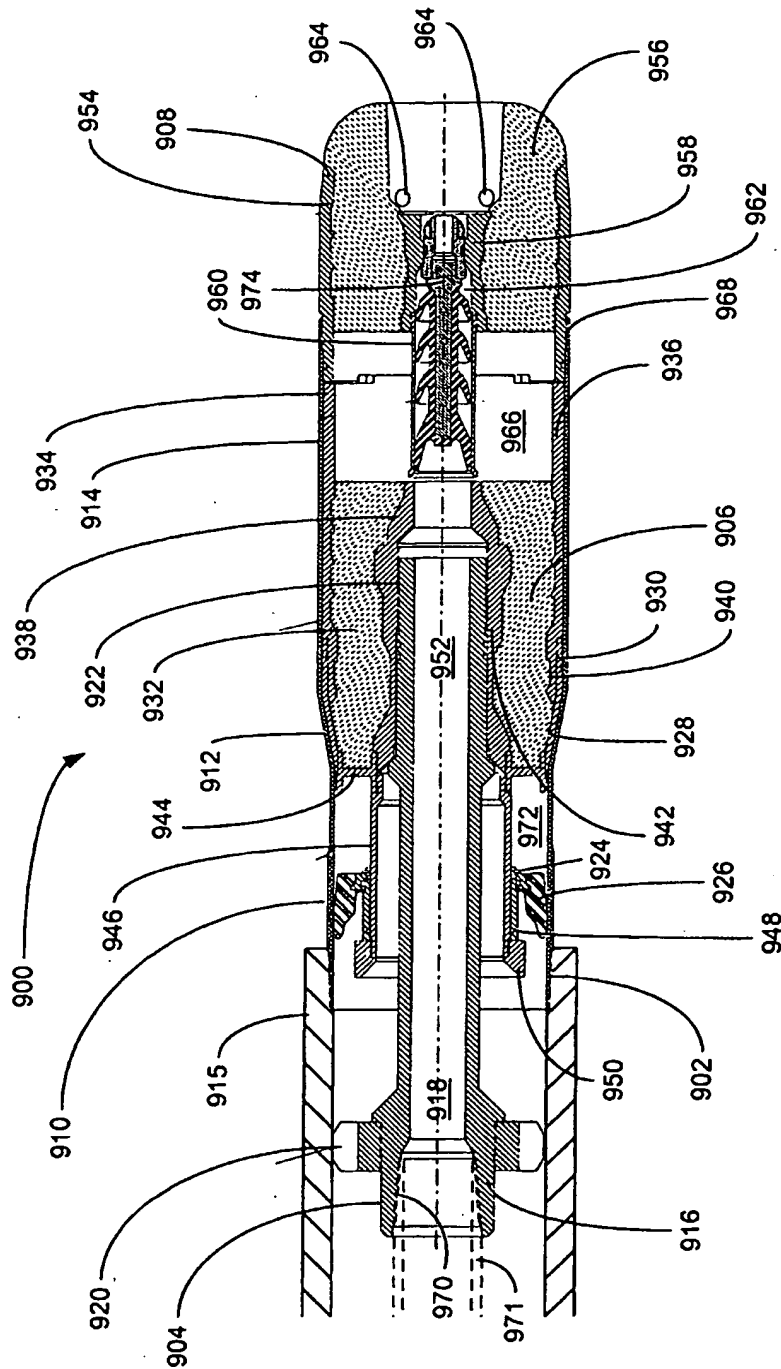


FIGURE 9

WO 01/04535

11/83

PCT/US00/18635

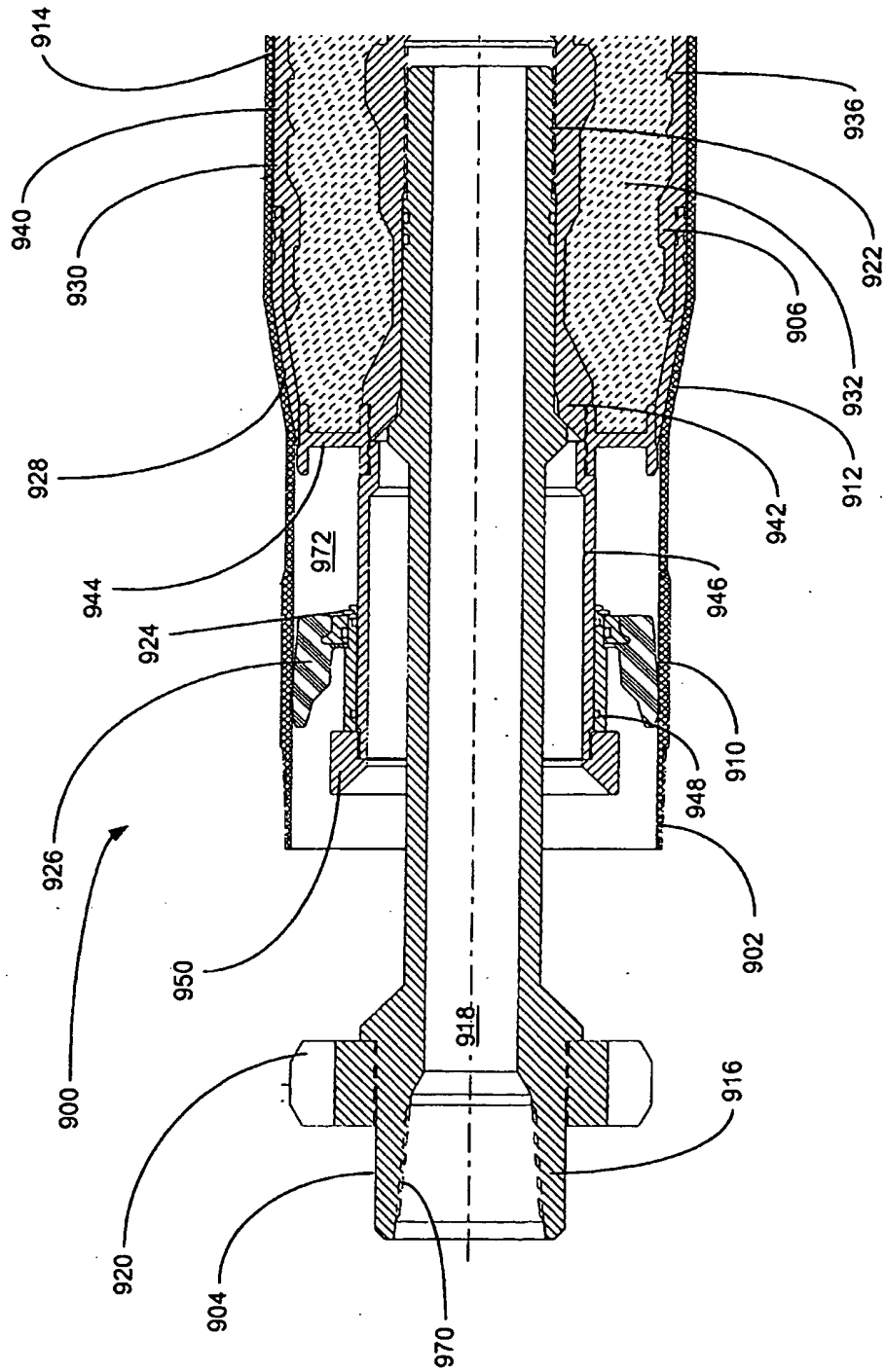


FIGURE 9a

WO 01/04535

12/83

PCT/US00/18635

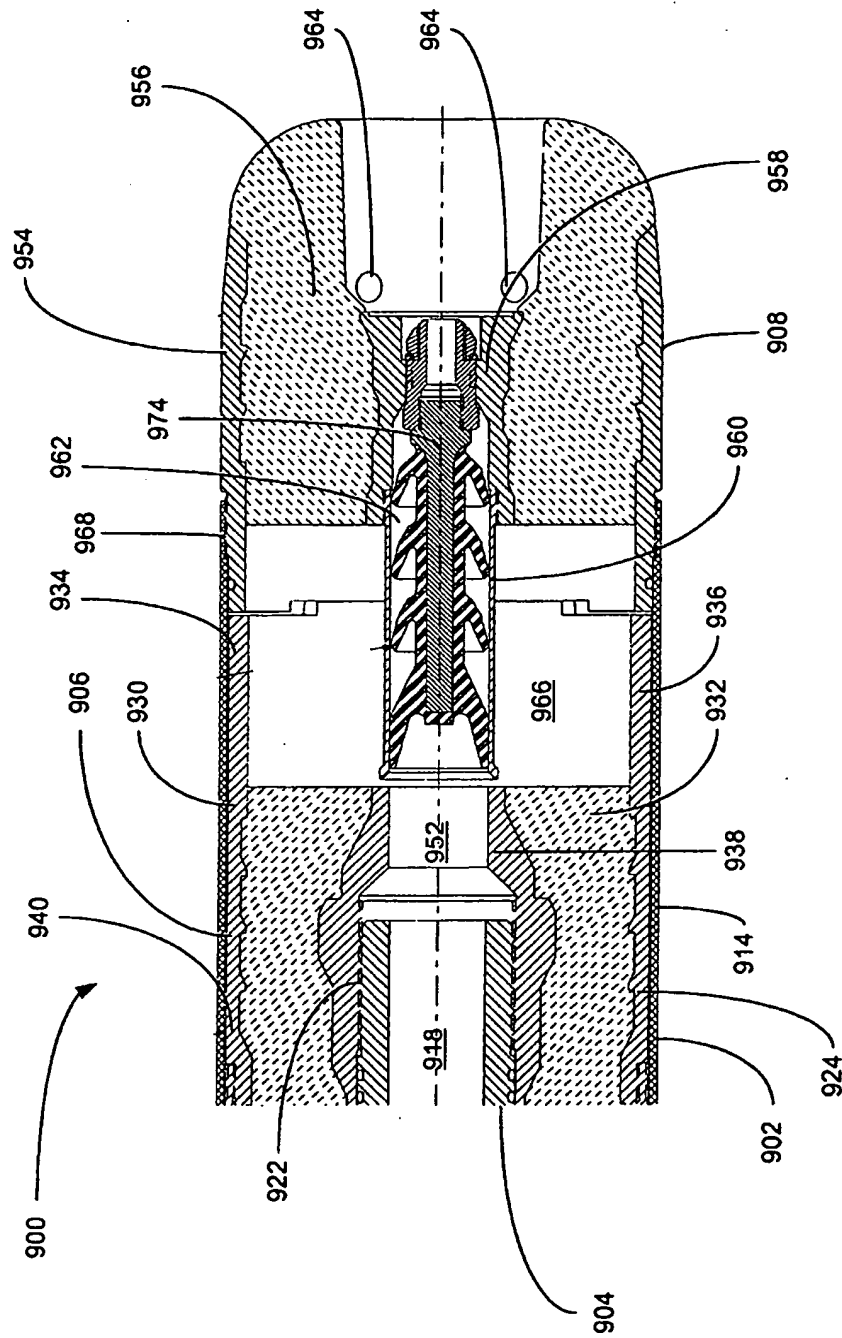


FIGURE 9b

WO 01/04535

13/83

PCT/US00/18635

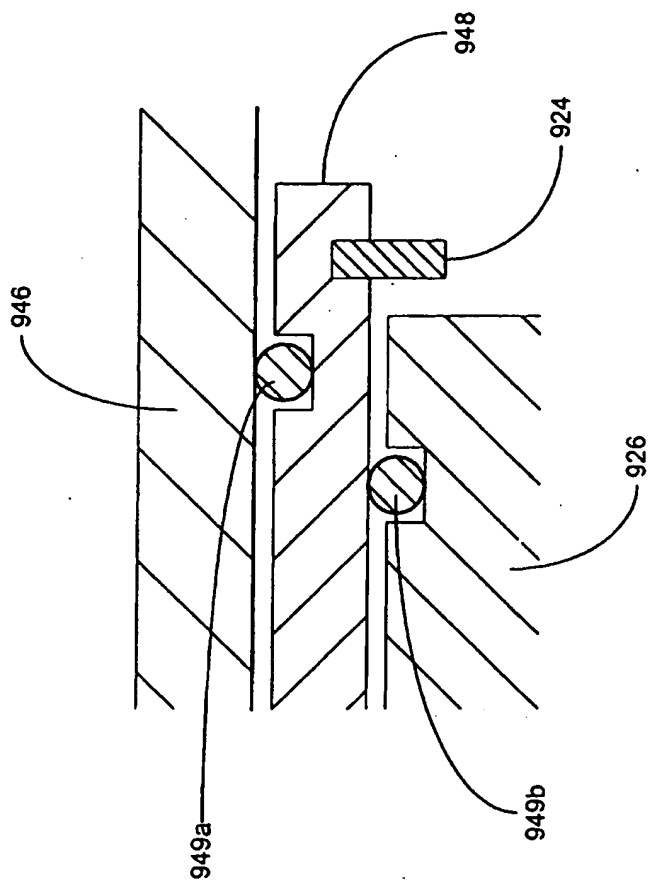


FIGURE 9C



WO 01/04535

PCT/US00/18635

14/83

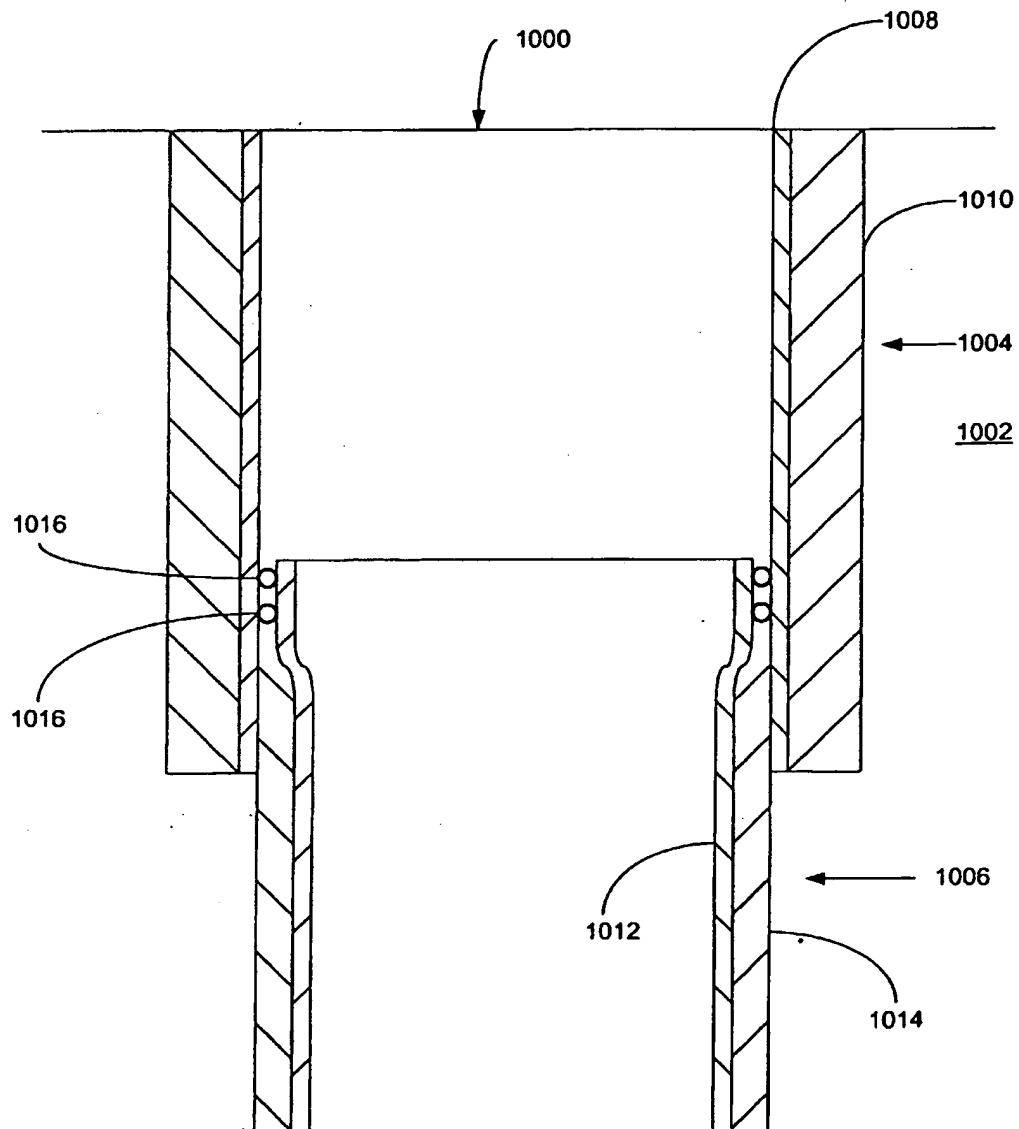


FIGURE 10a

WO 01/04535

PCT/US00/18635

15/83

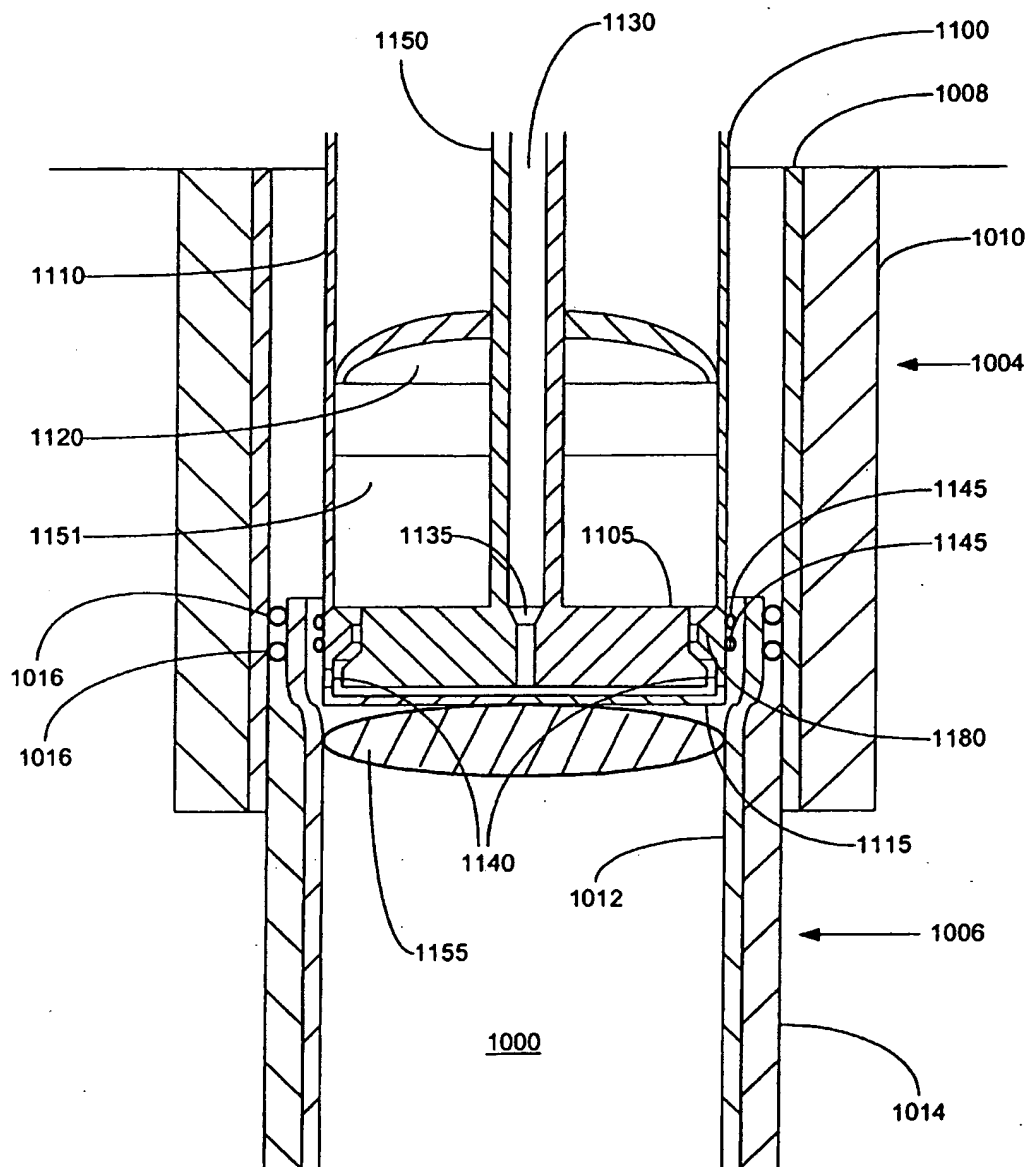


FIGURE 10b

WO 01/04535

PCT/US00/18635

16/83

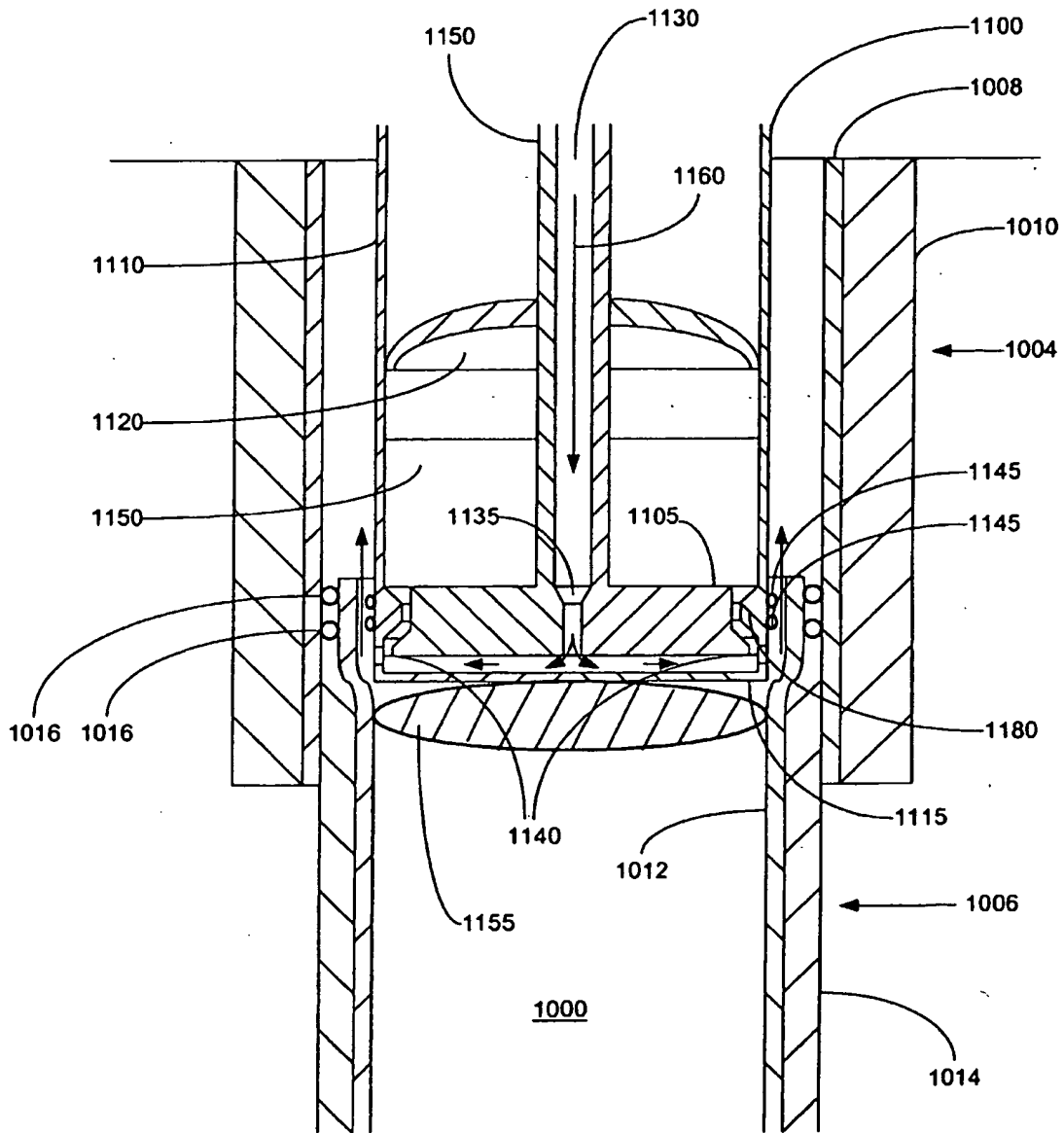


FIGURE 10c

WO 01/04535

PCT/US00/18635

17/83

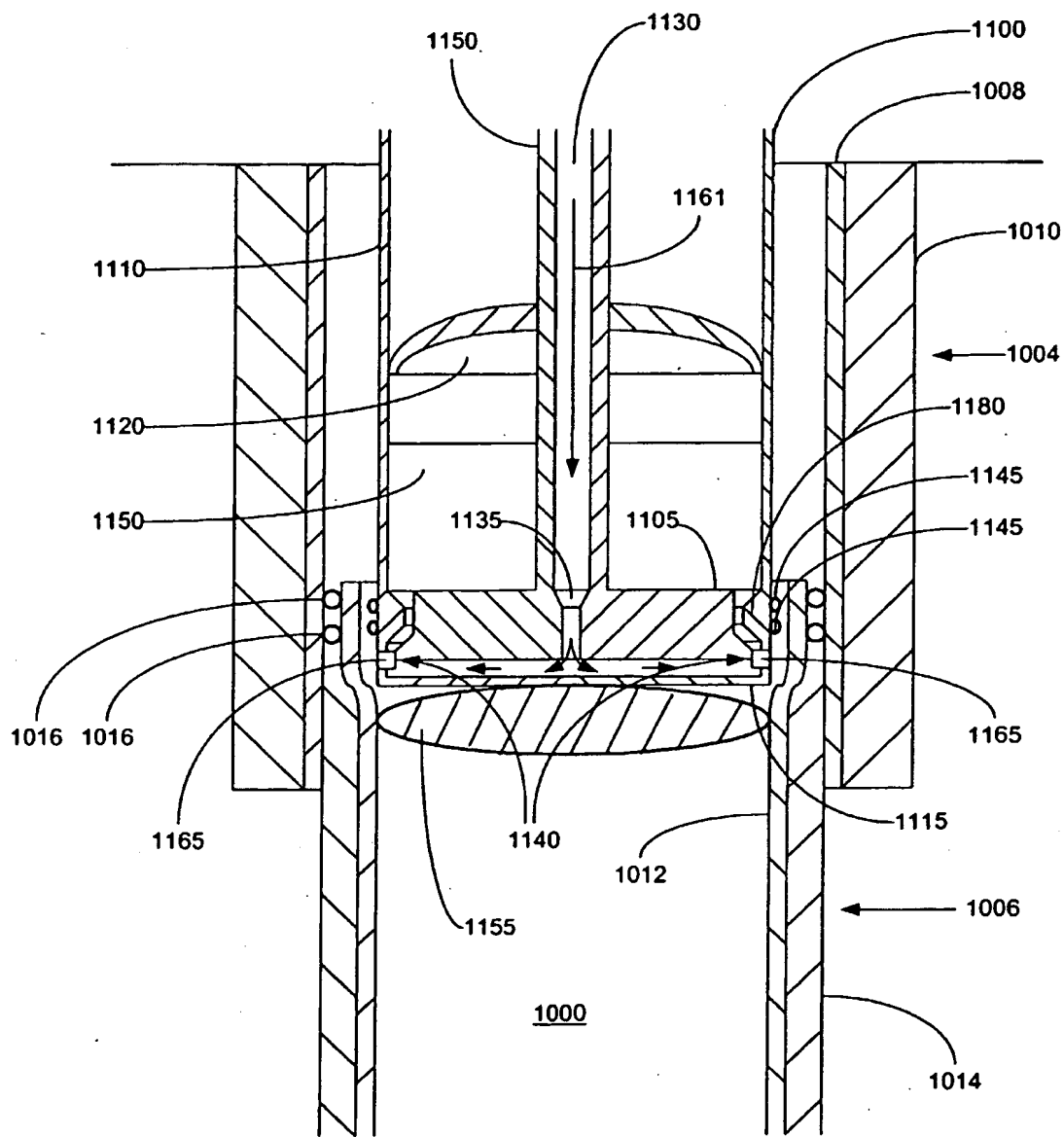


FIGURE 10d



WO 01/04535

PCT/US00/18635

19/83

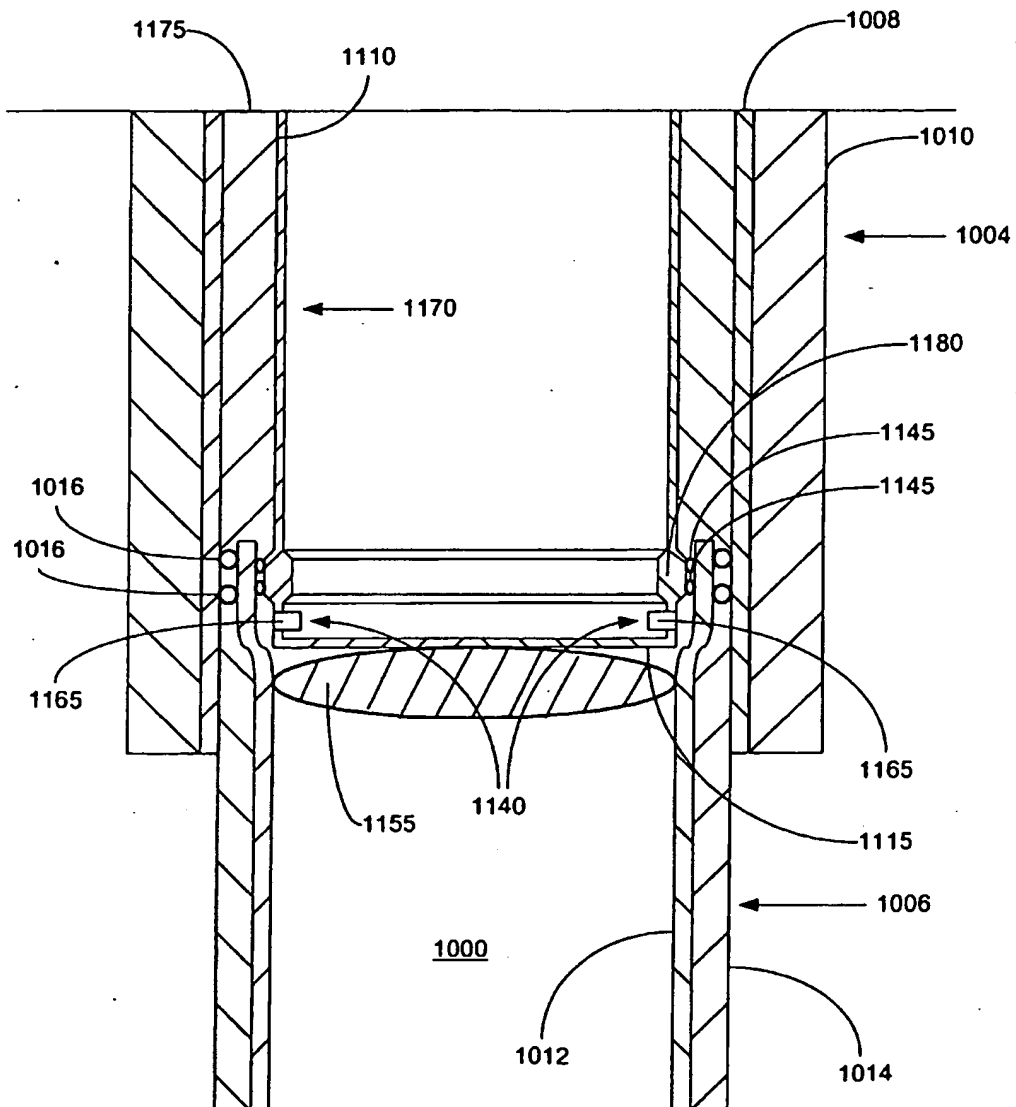


FIGURE 10f

WO 01/04535

PCT/US00/18635

20/83

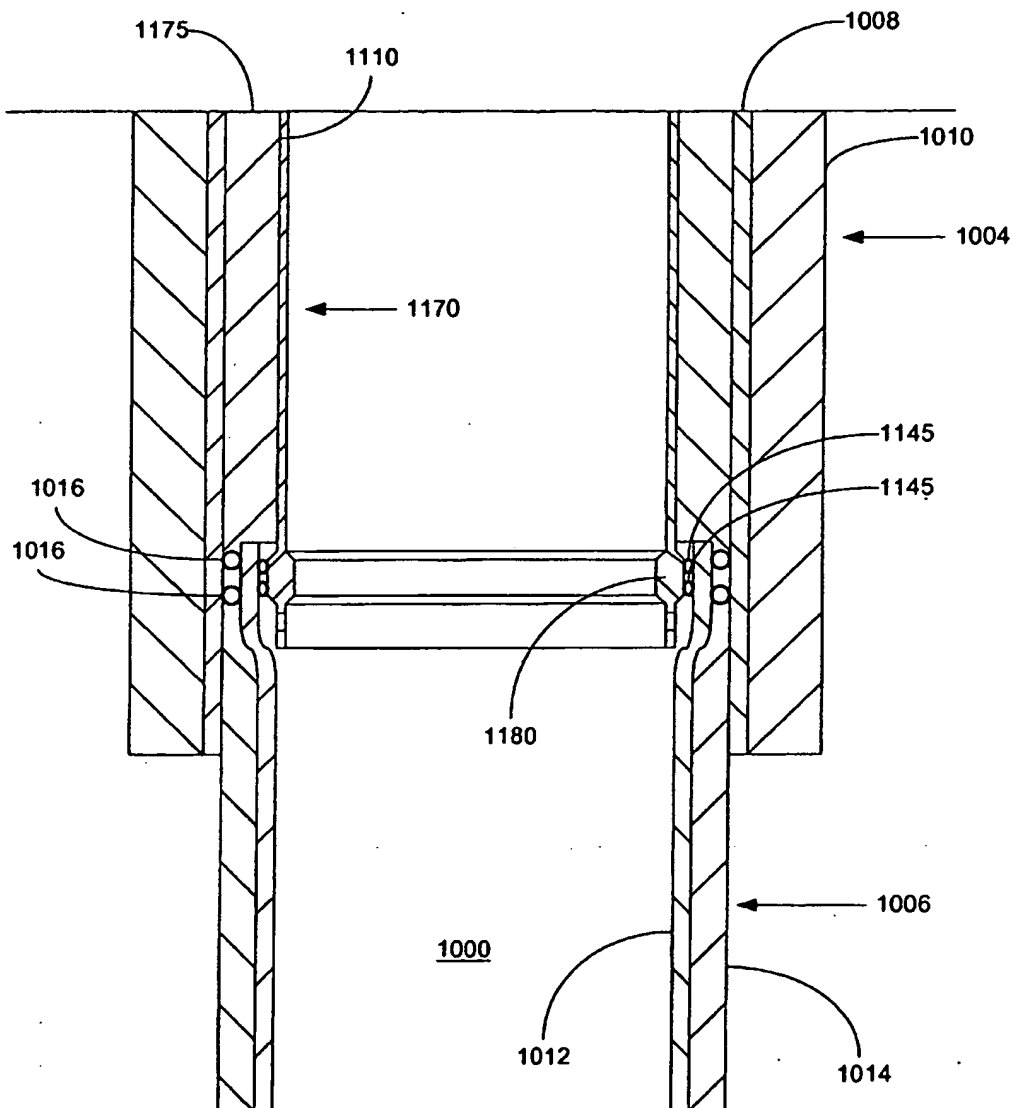


FIGURE 10g

WO 01/04535

PCT/US00/18635

21/83

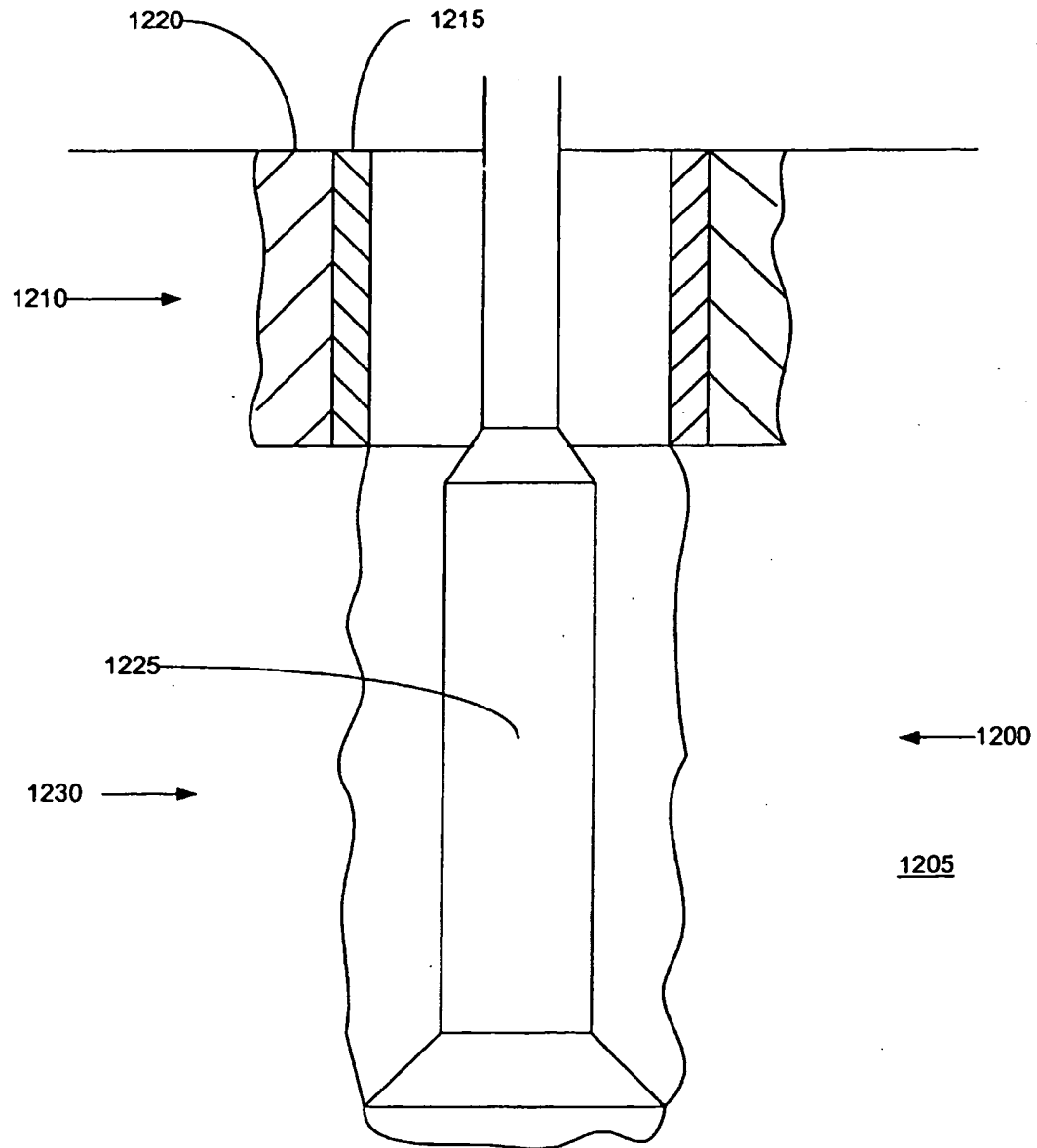


FIGURE 11a



WO 01/04535

PCT/US00/18635

22/83

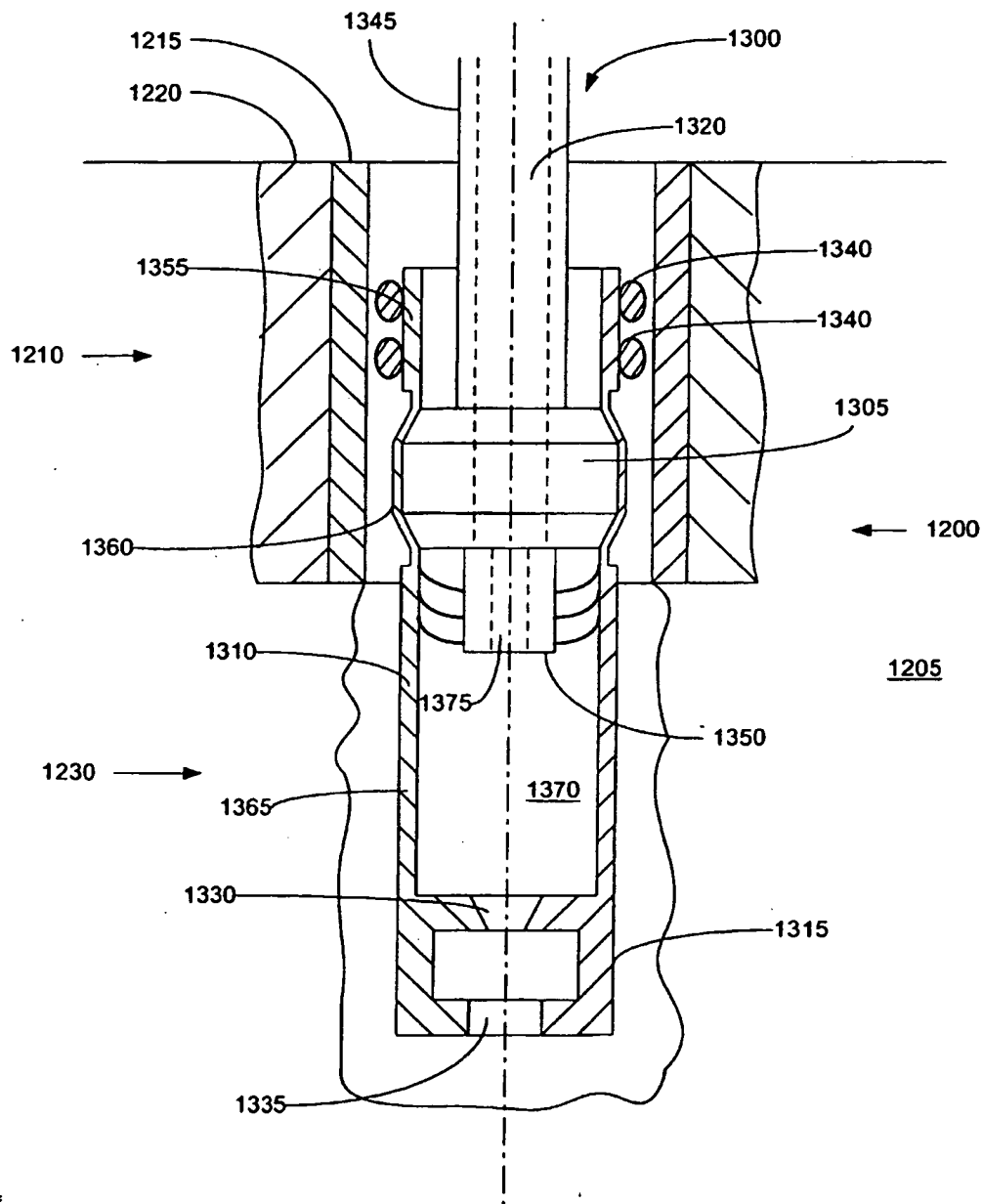
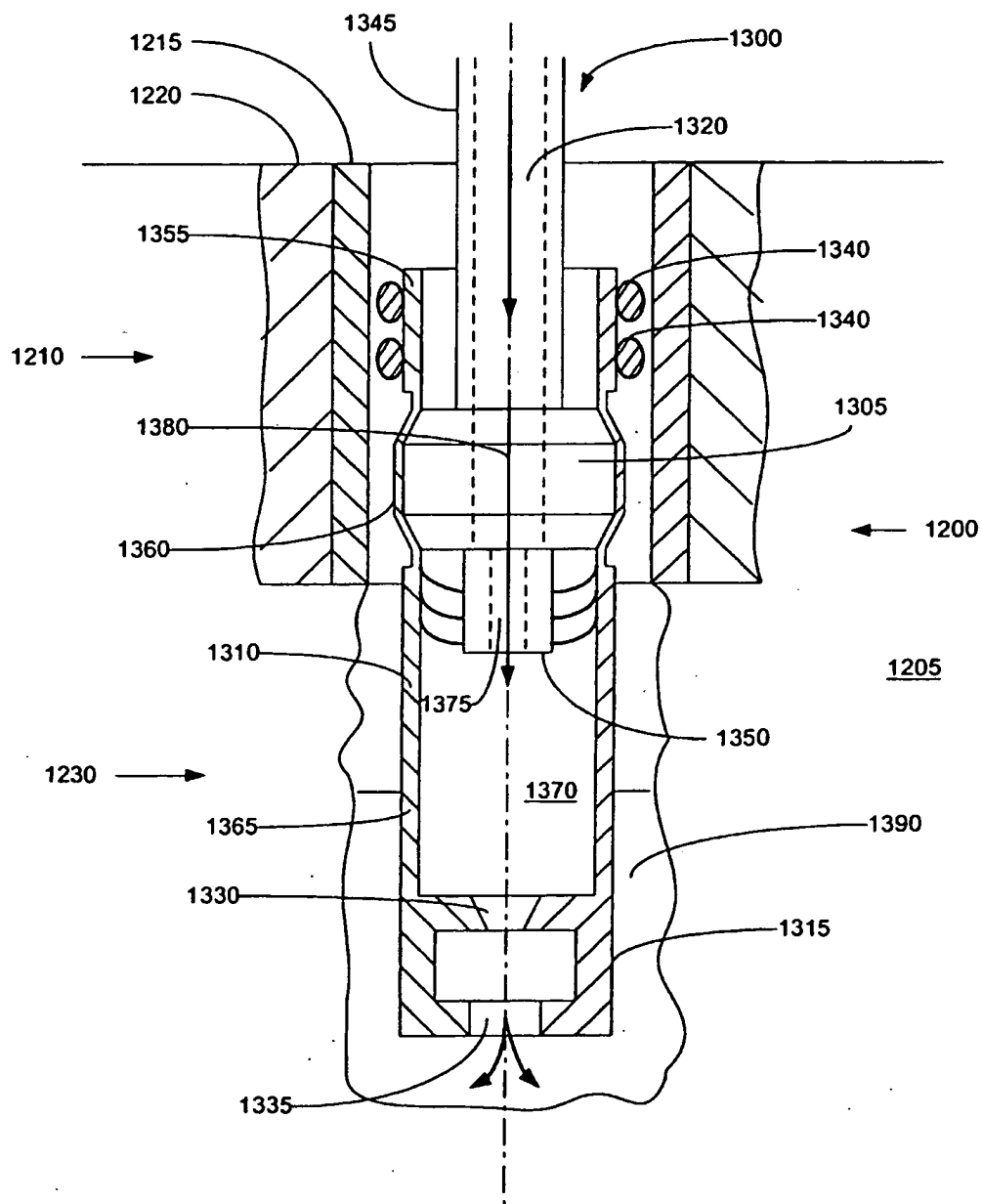


FIGURE 11b

WO 01/04535

PCT/US00/18635

23/83





WO 01/04535

PCT/US00/18635

25/83

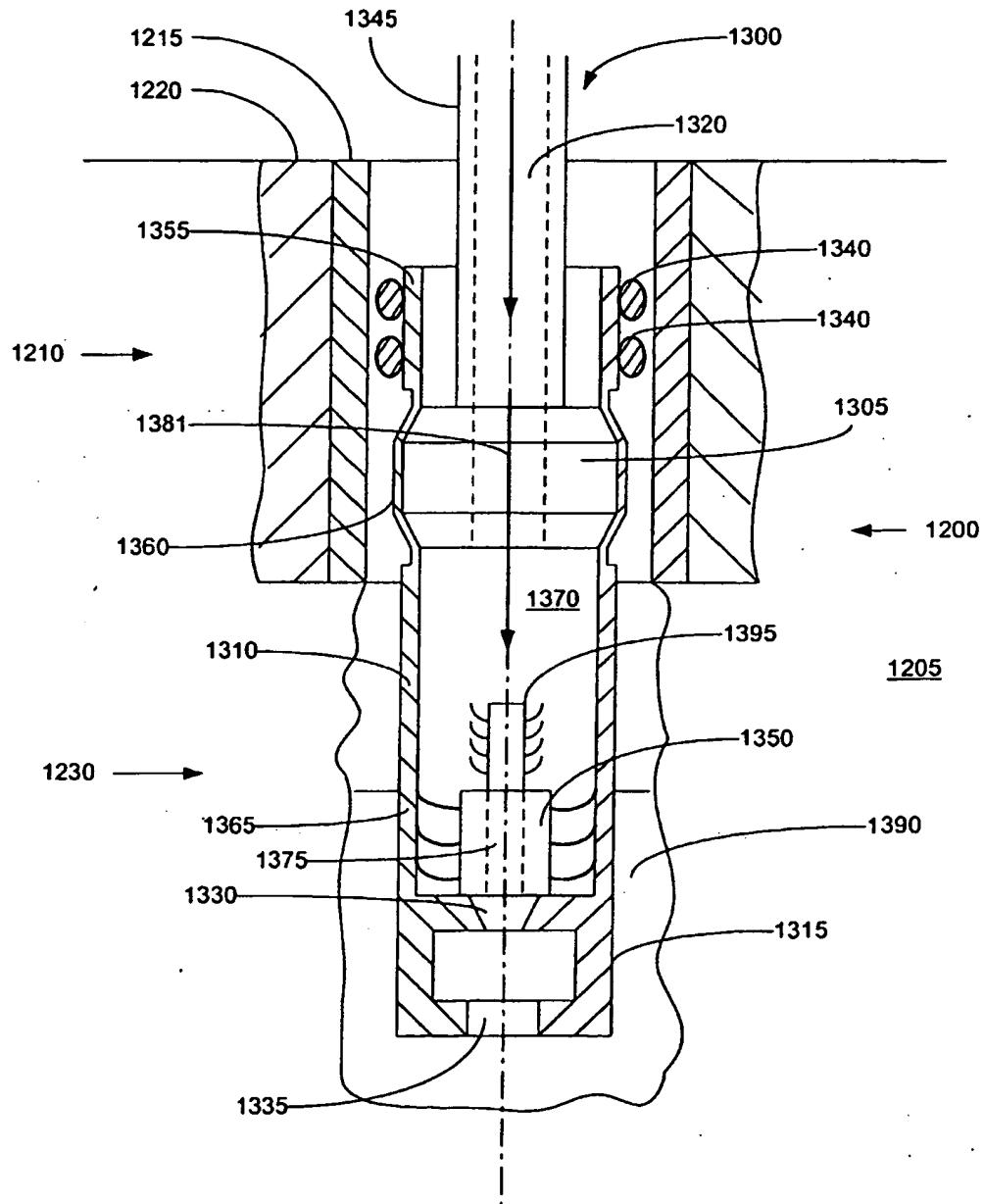


FIGURE 11e

WO 01/04535

PCT/US00/18635

26/83

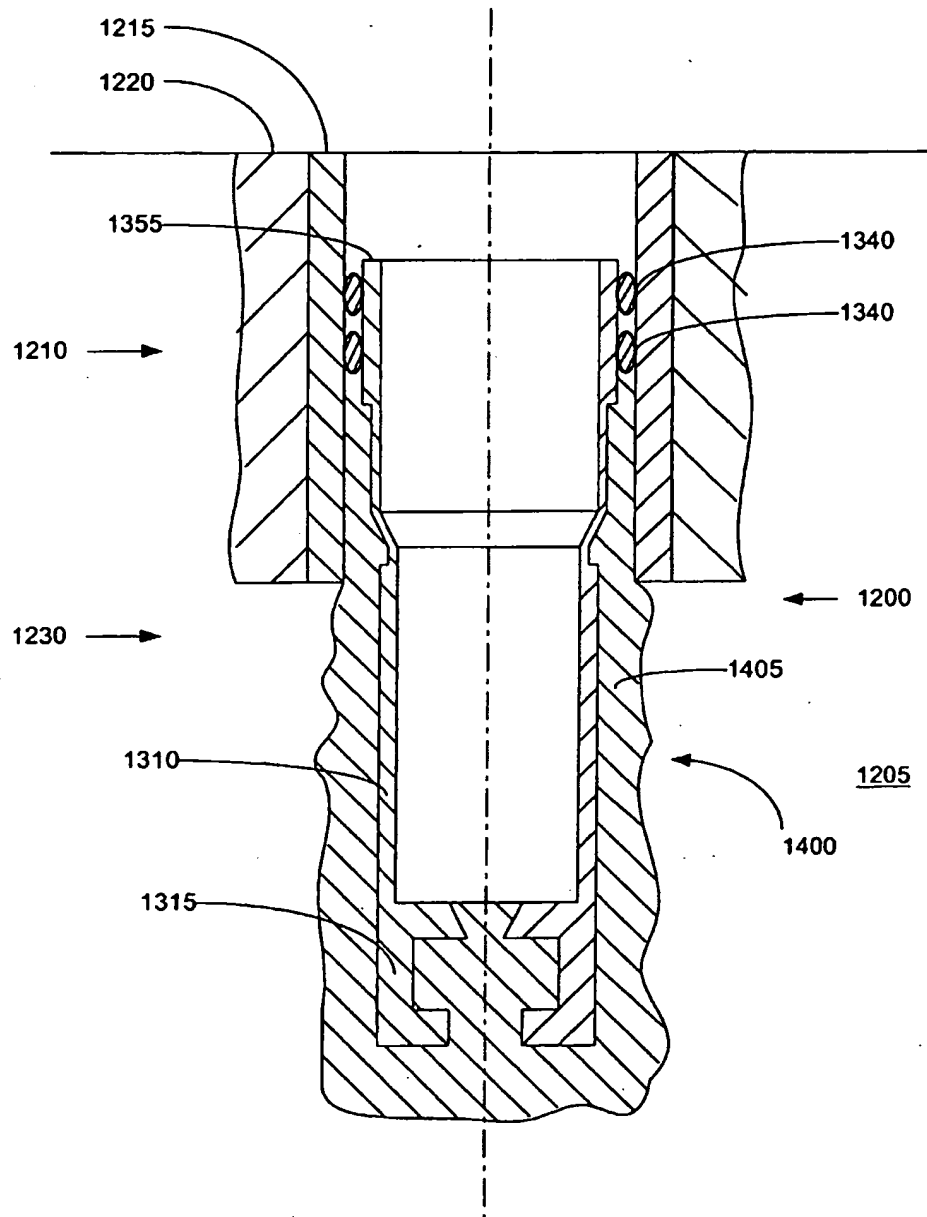


FIGURE 11f

WO 01/04535

PCT/US00/18635

27/83

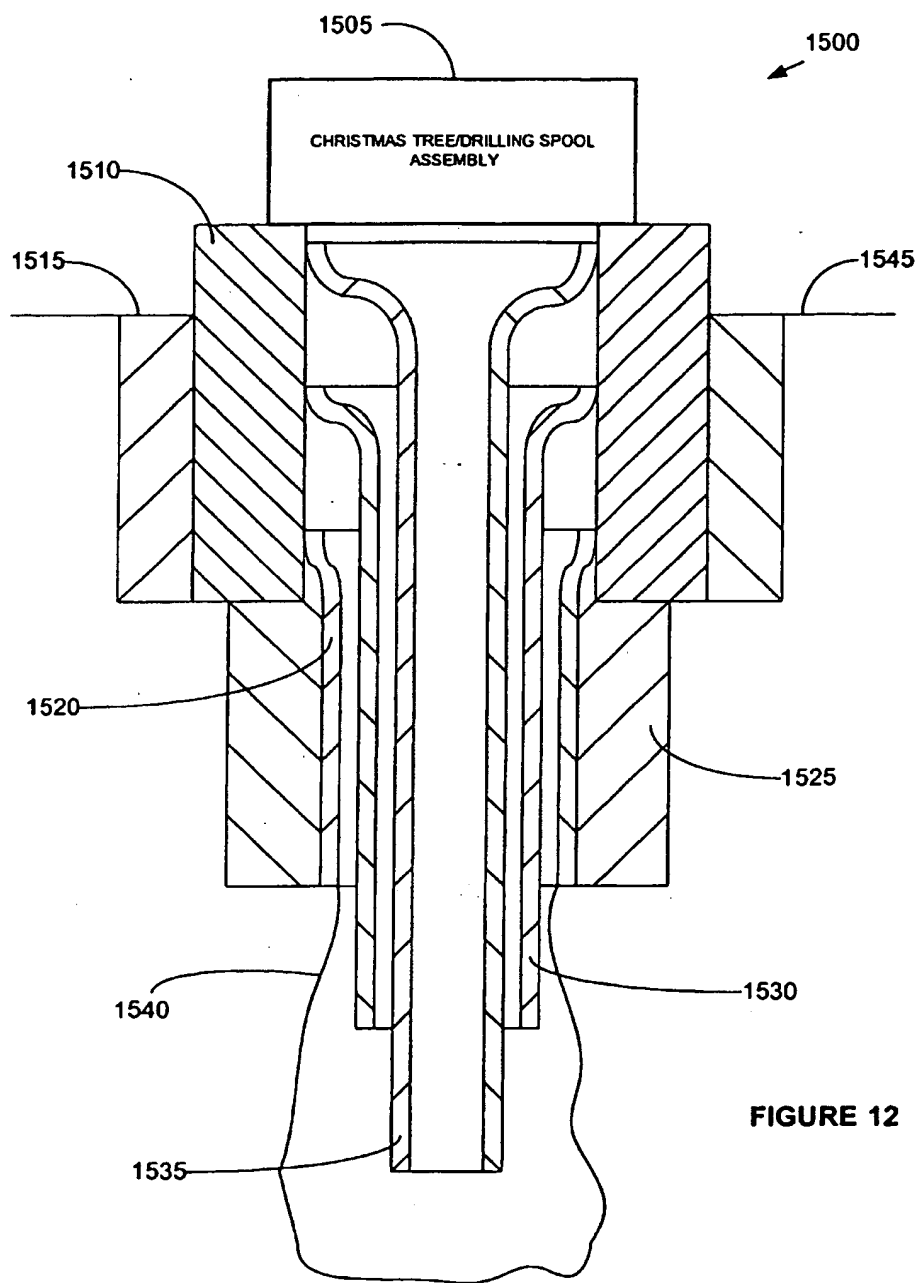


FIGURE 12

WO 01/04535

PCT/US00/18635

28/83

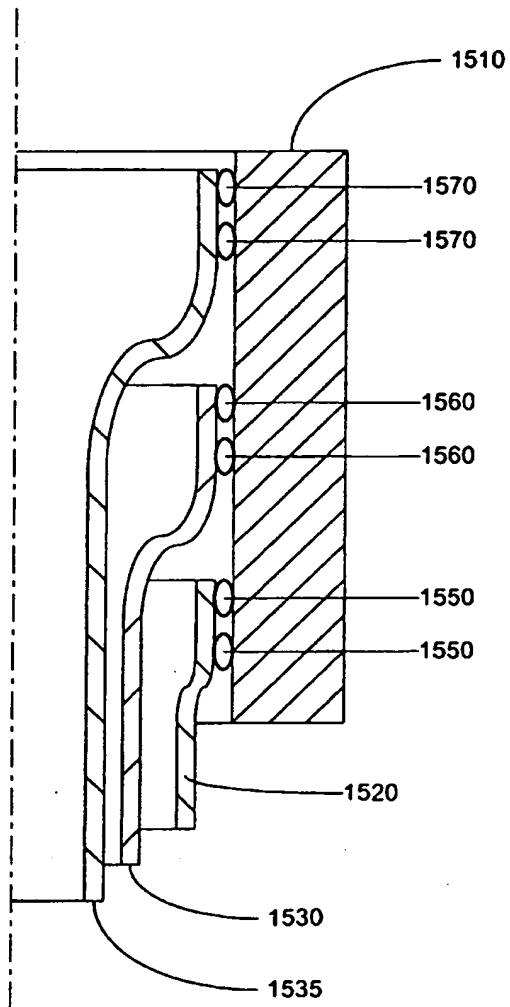


FIGURE 13

WO 01/04535

PCT/US00/18635

29/83

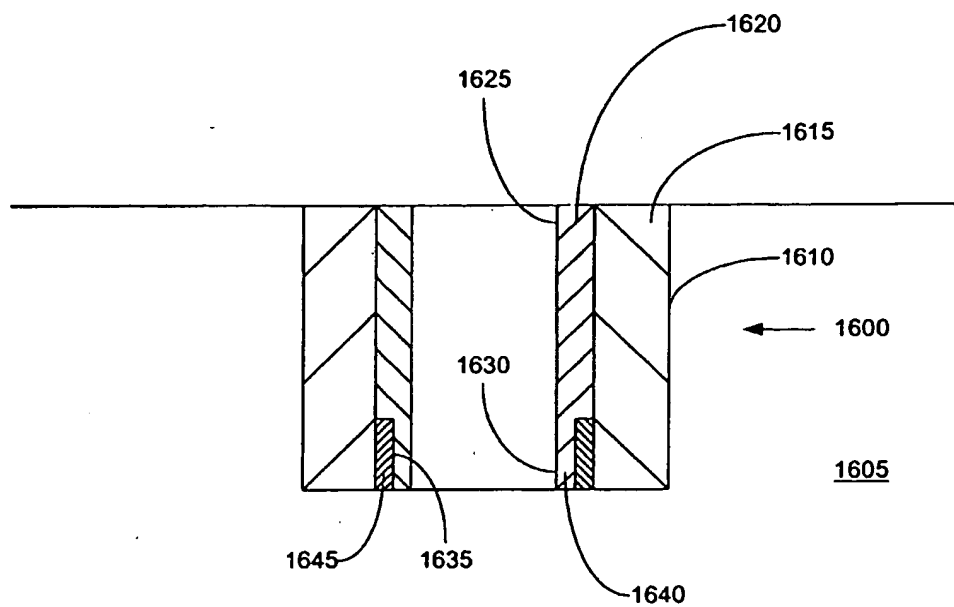


FIGURE 14a



WO 01/04535

PCT/US00/18635

30/83

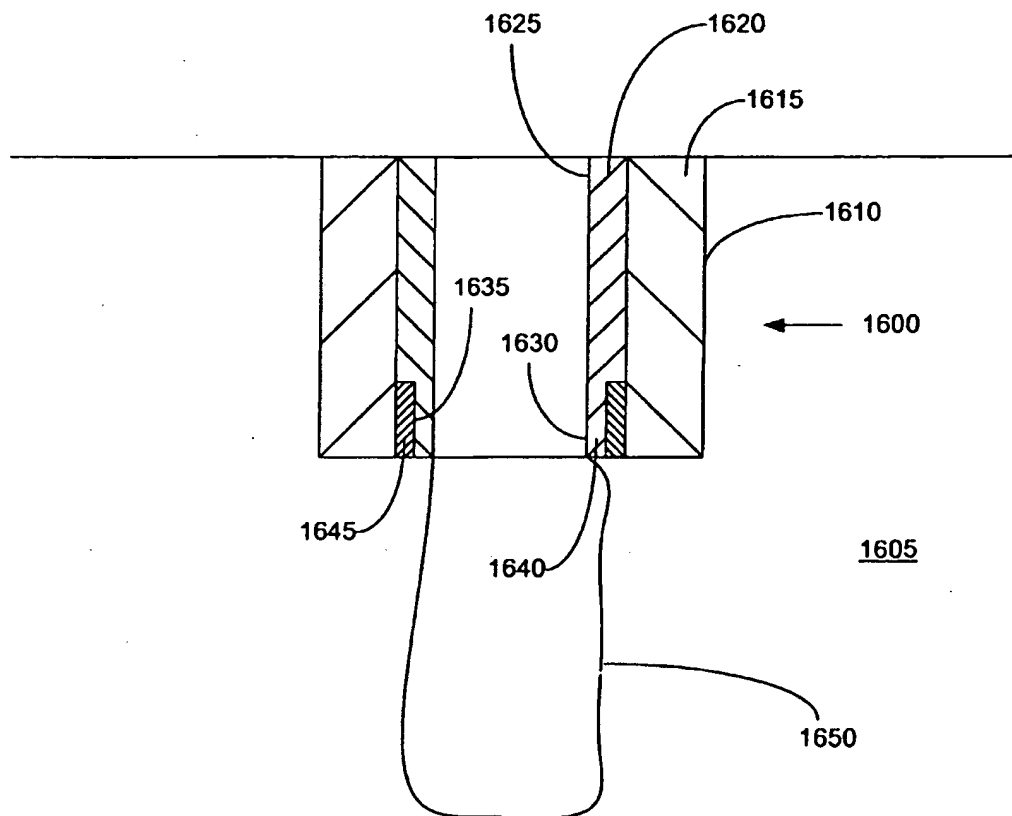


FIGURE 14b

WO 01/04535

PCT/US00/18635

31/83

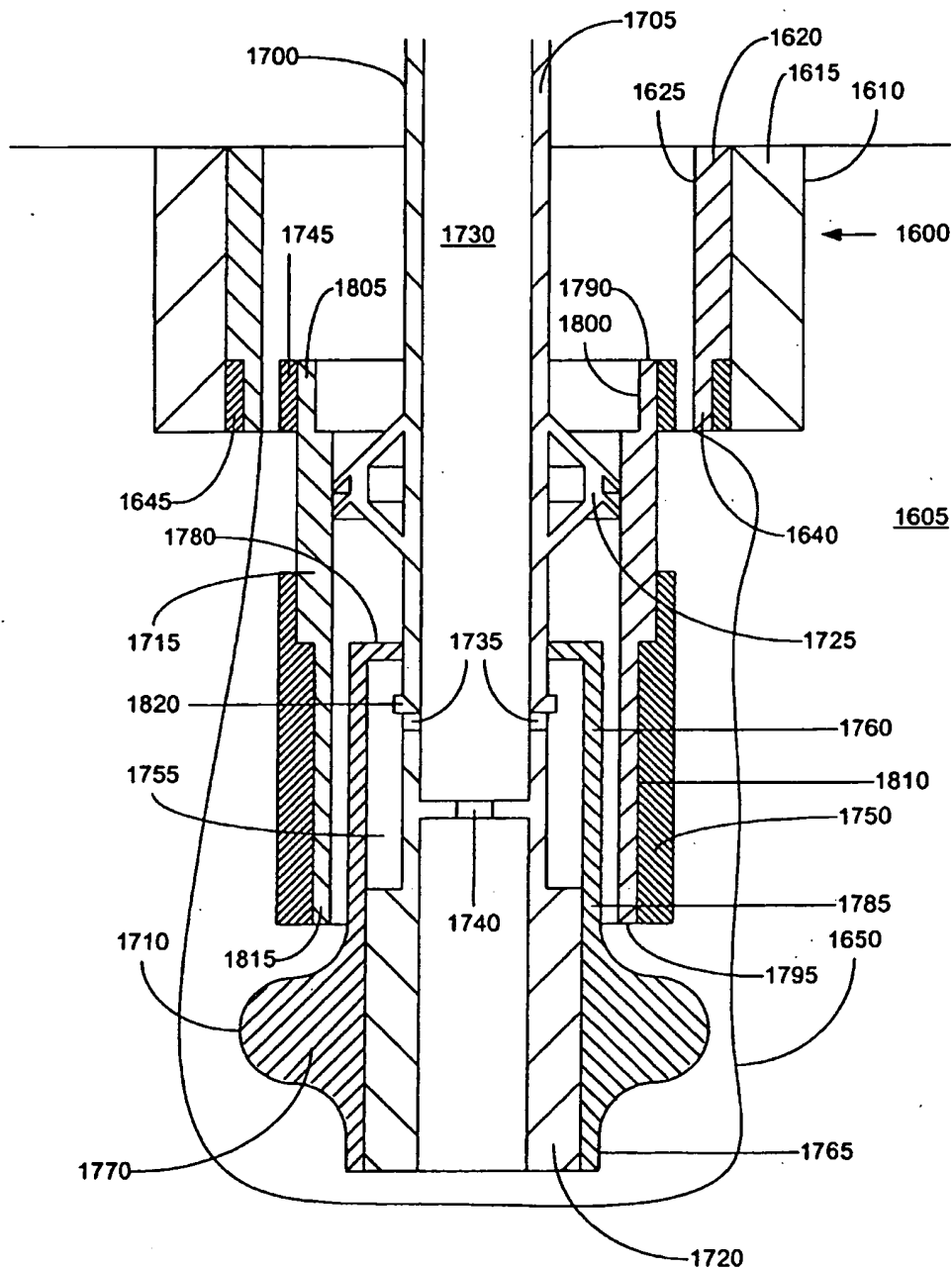
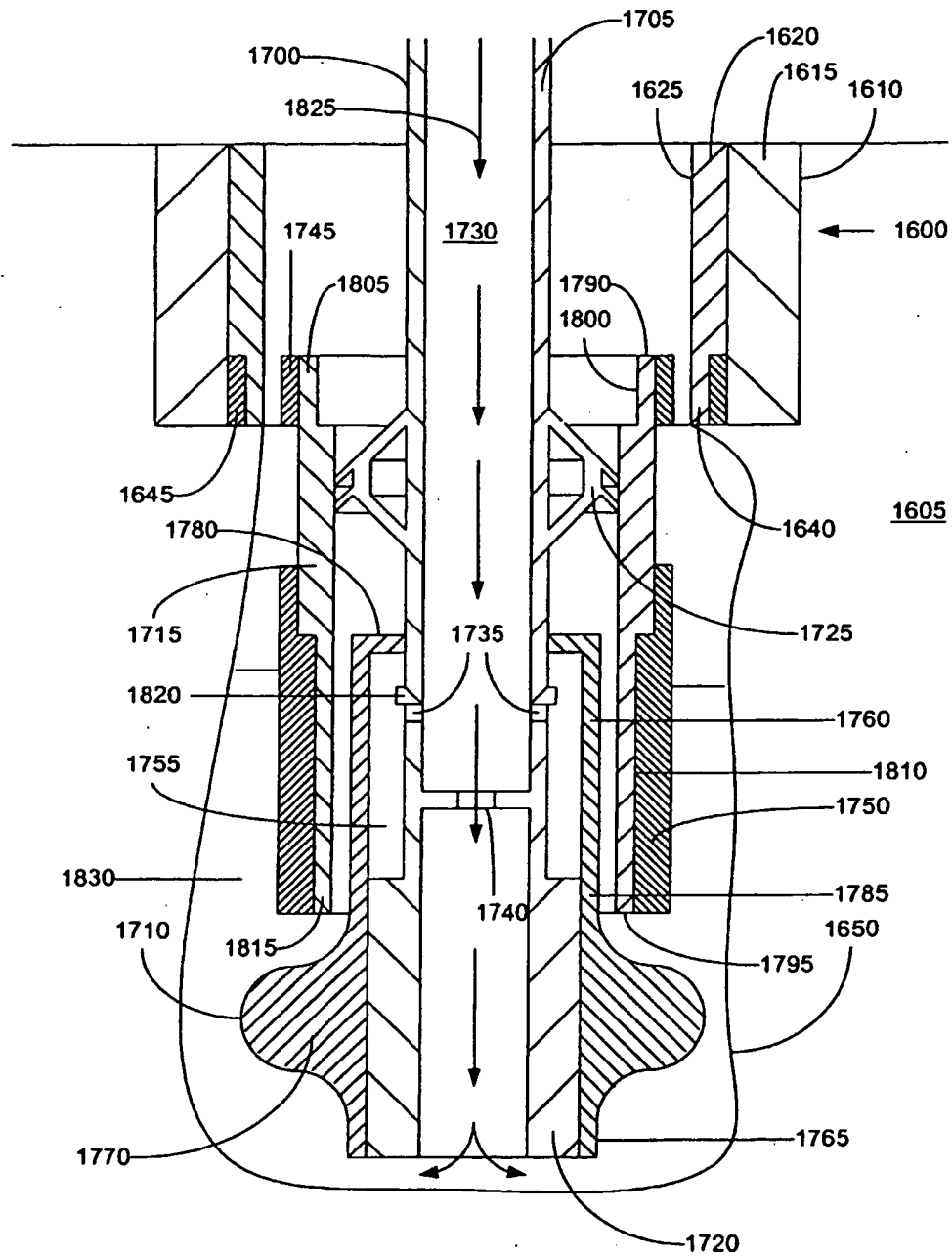


FIGURE 14c

**WO 01/04535**

**PCT/US00/18635**

32/83



**FIGURE 14d**

WO 01/04535

PCT/US00/18635

33/83

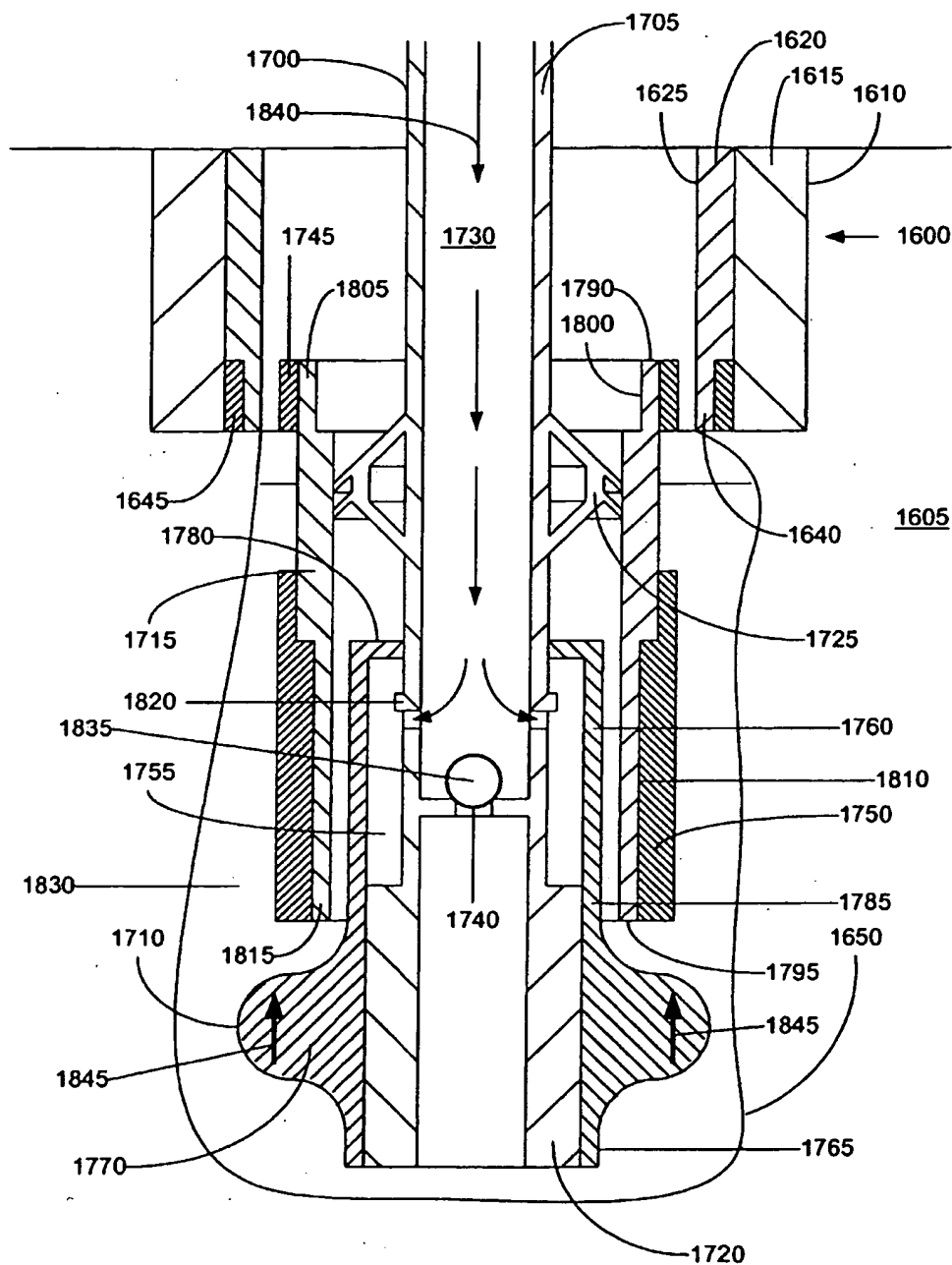


FIGURE 14e

WO 01/04535

PCT/US00/18635

34/83

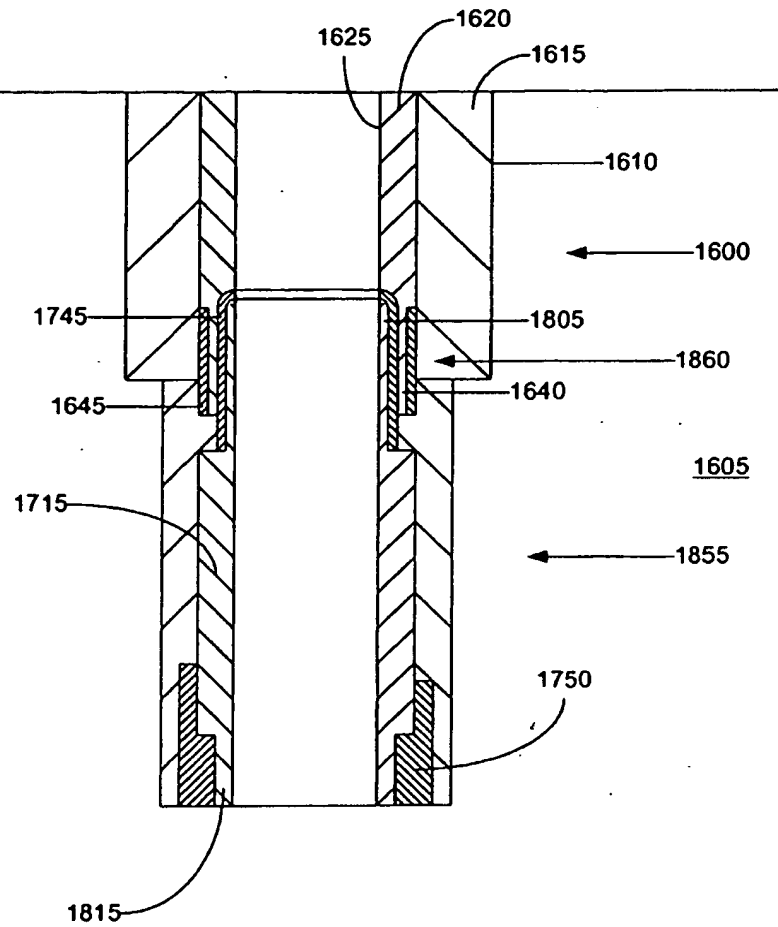


FIGURE 14f

WO 01/04535

35/83

PCT/US00/18635

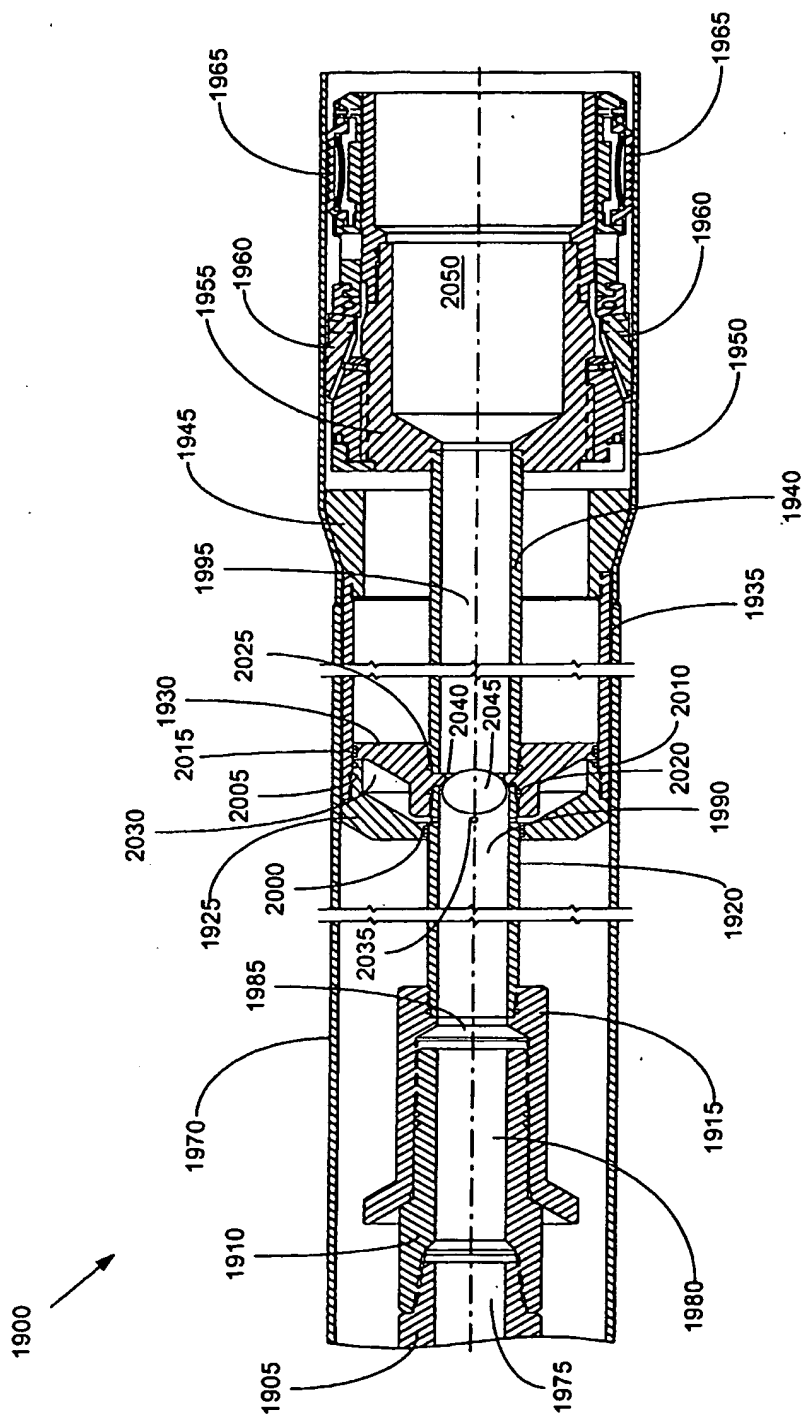


FIGURE 15

WO 01/04535

36/83

PCT/US00/18635

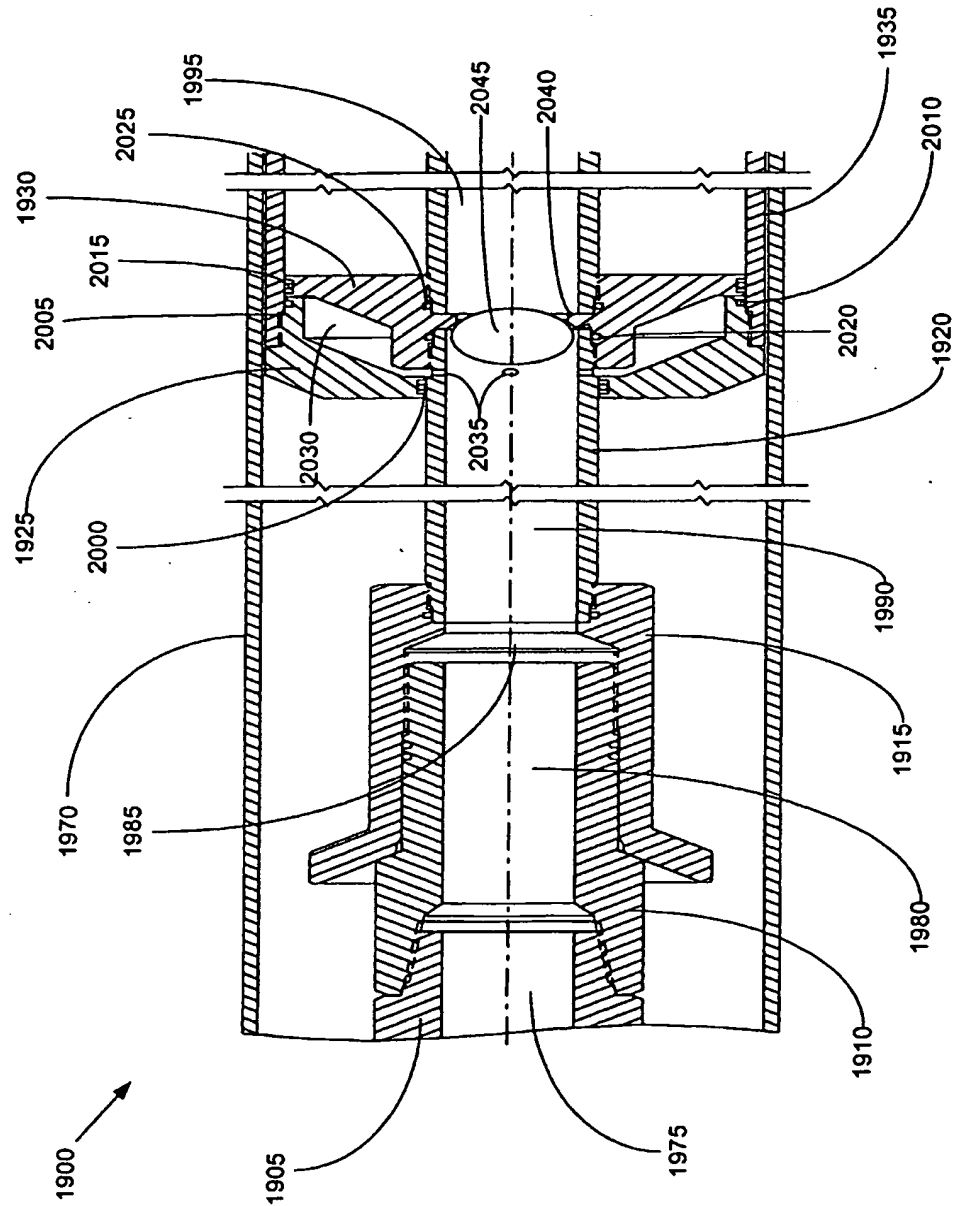
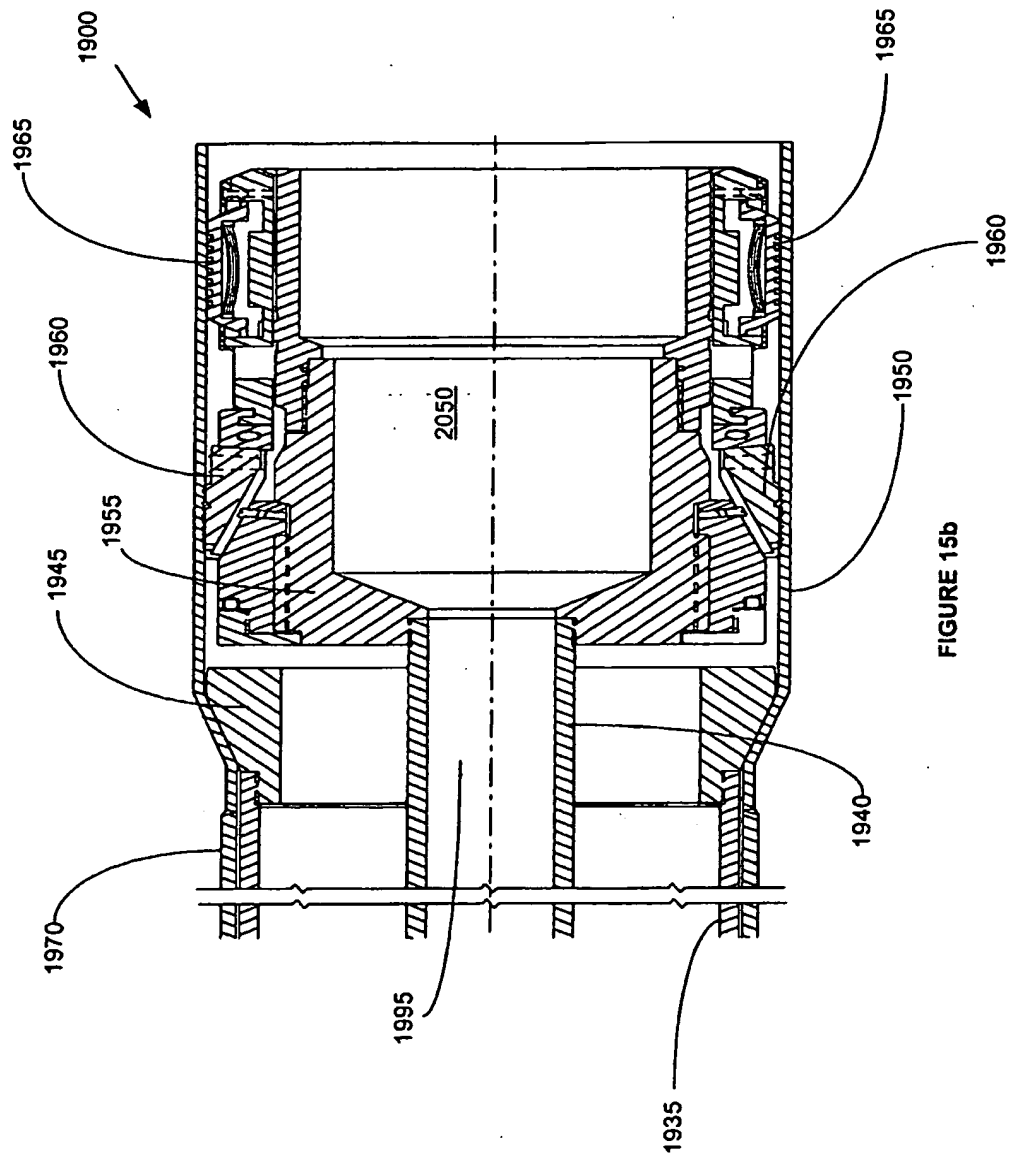


FIGURE 15a

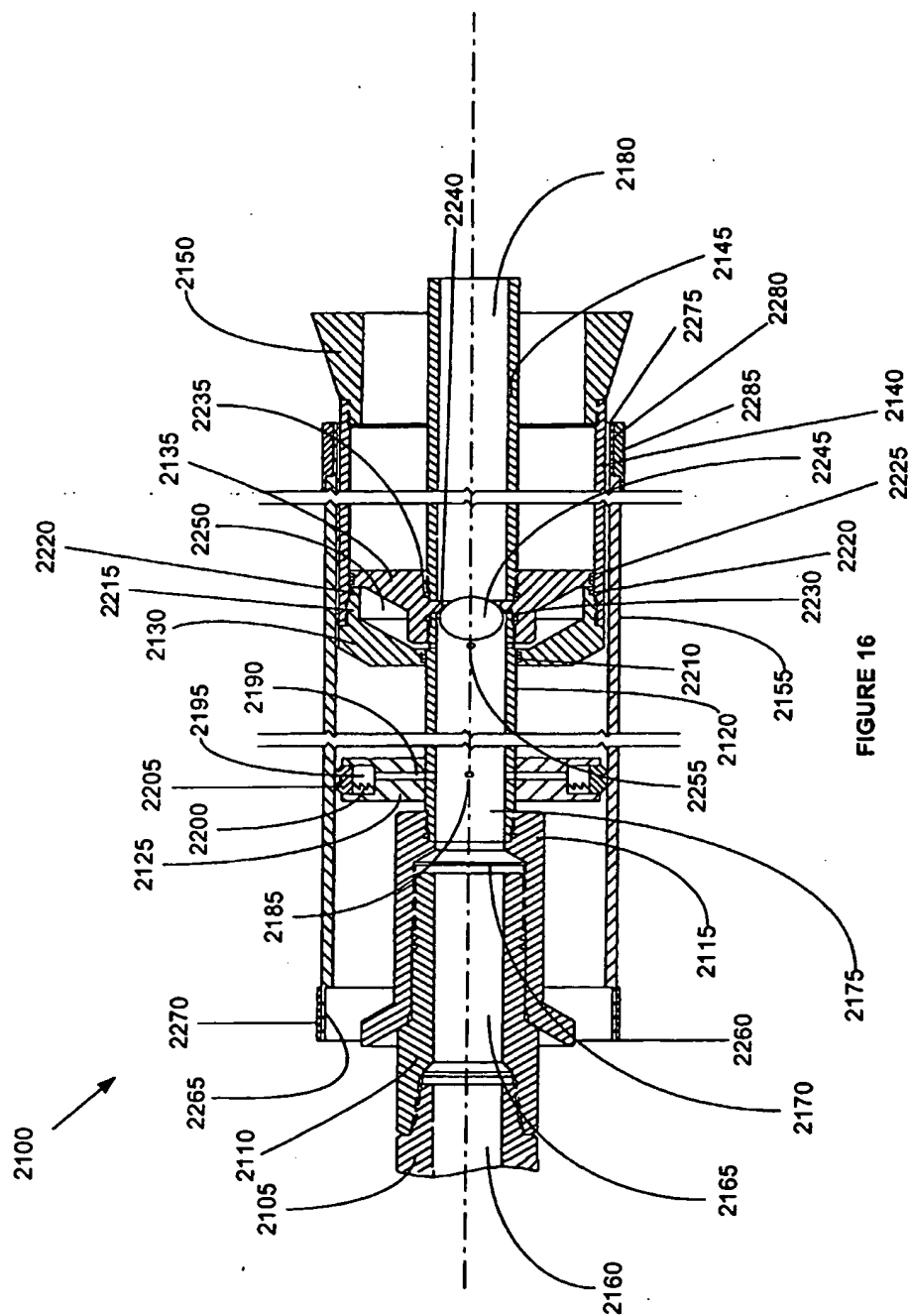
**WO 01/04535**

37/83

**PCT/US00/18635**



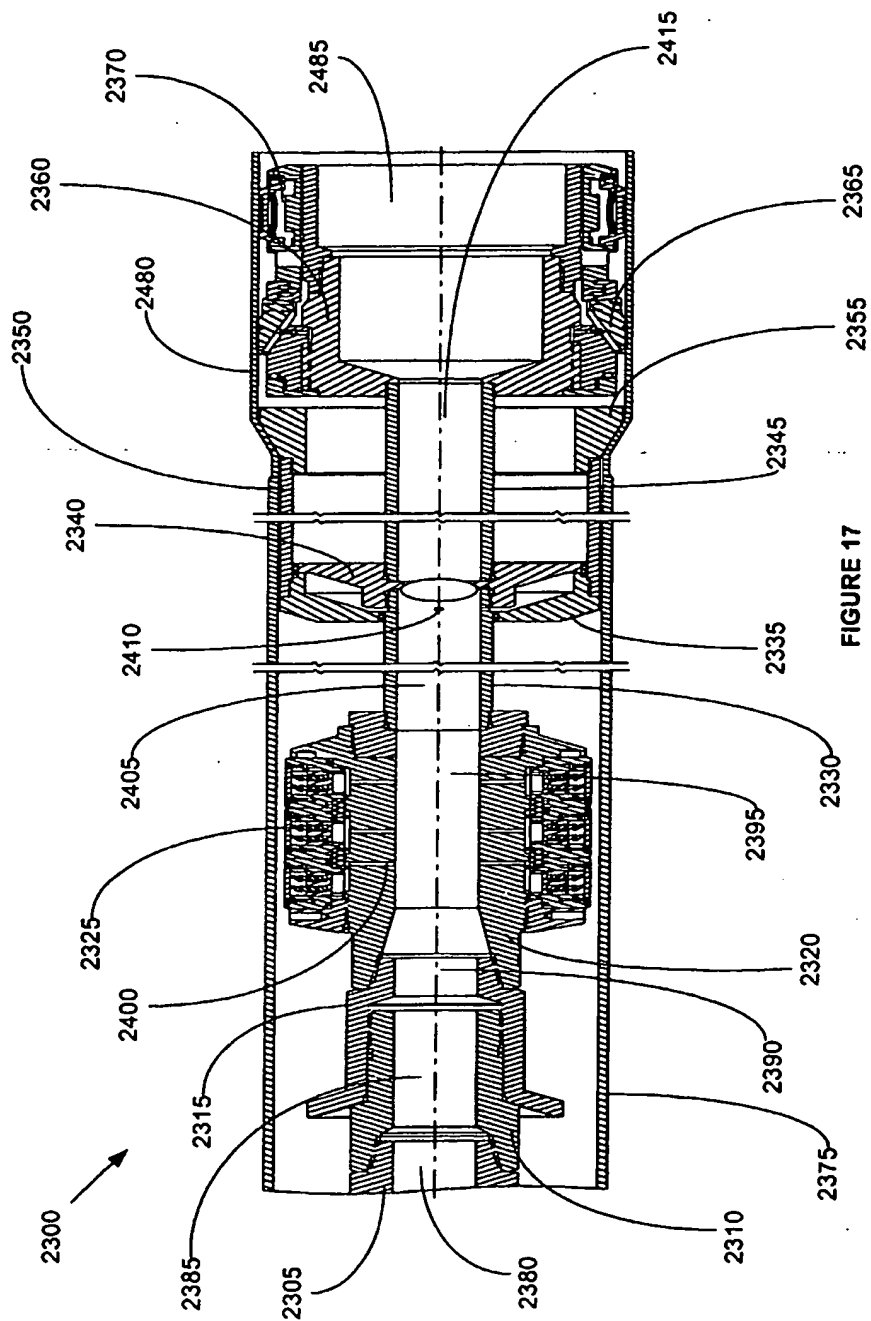




WO 01/04535

39/83

PCT/US00/18635



WO 01/04535

40/83

PCT/US00/18635

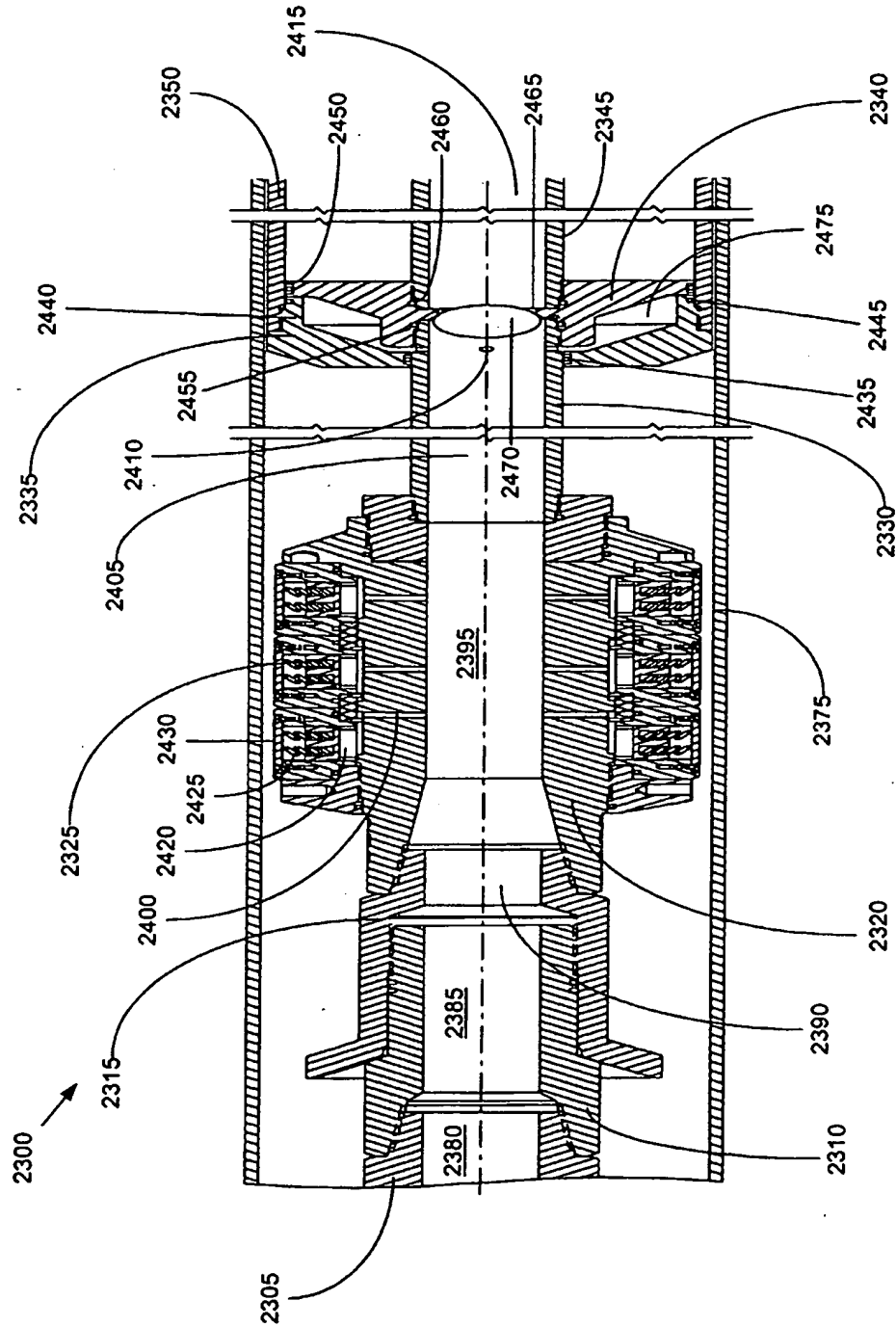
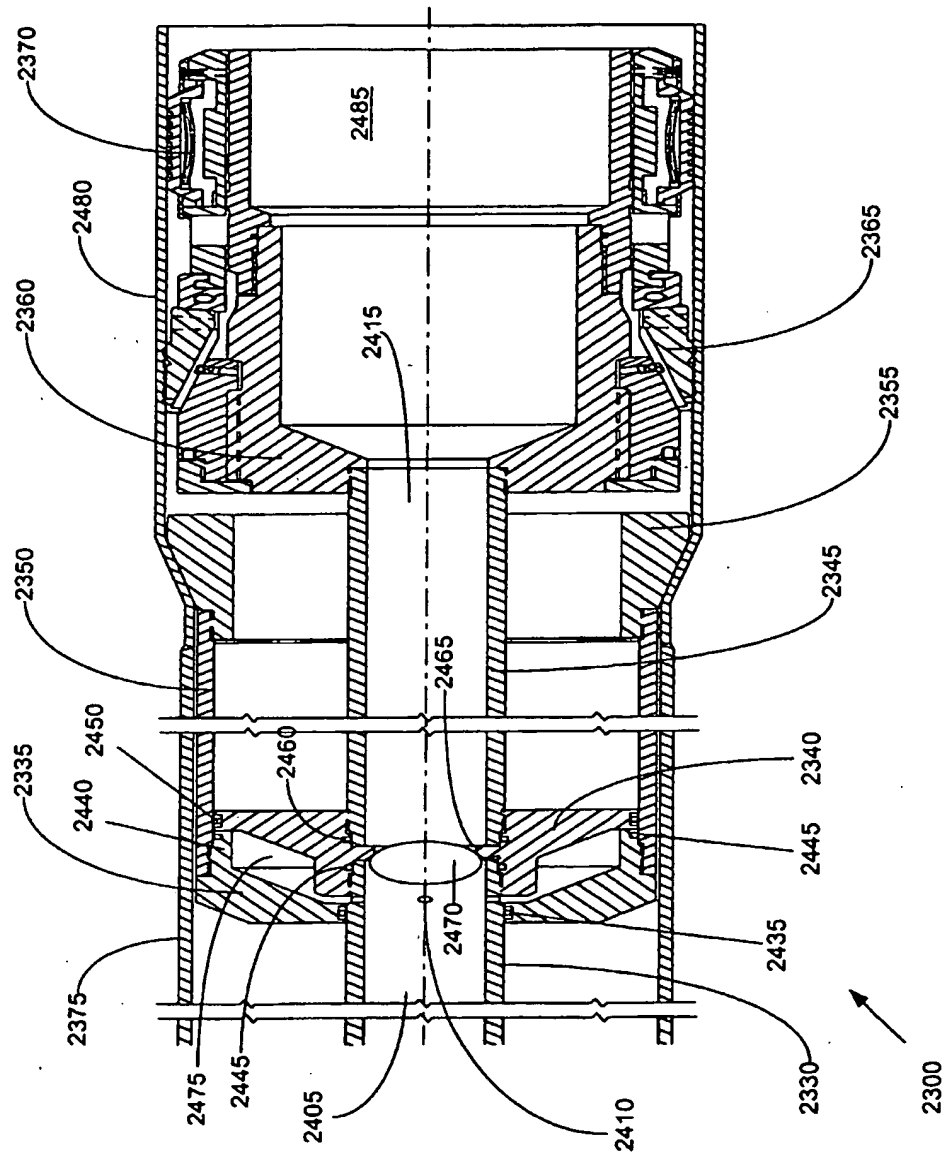


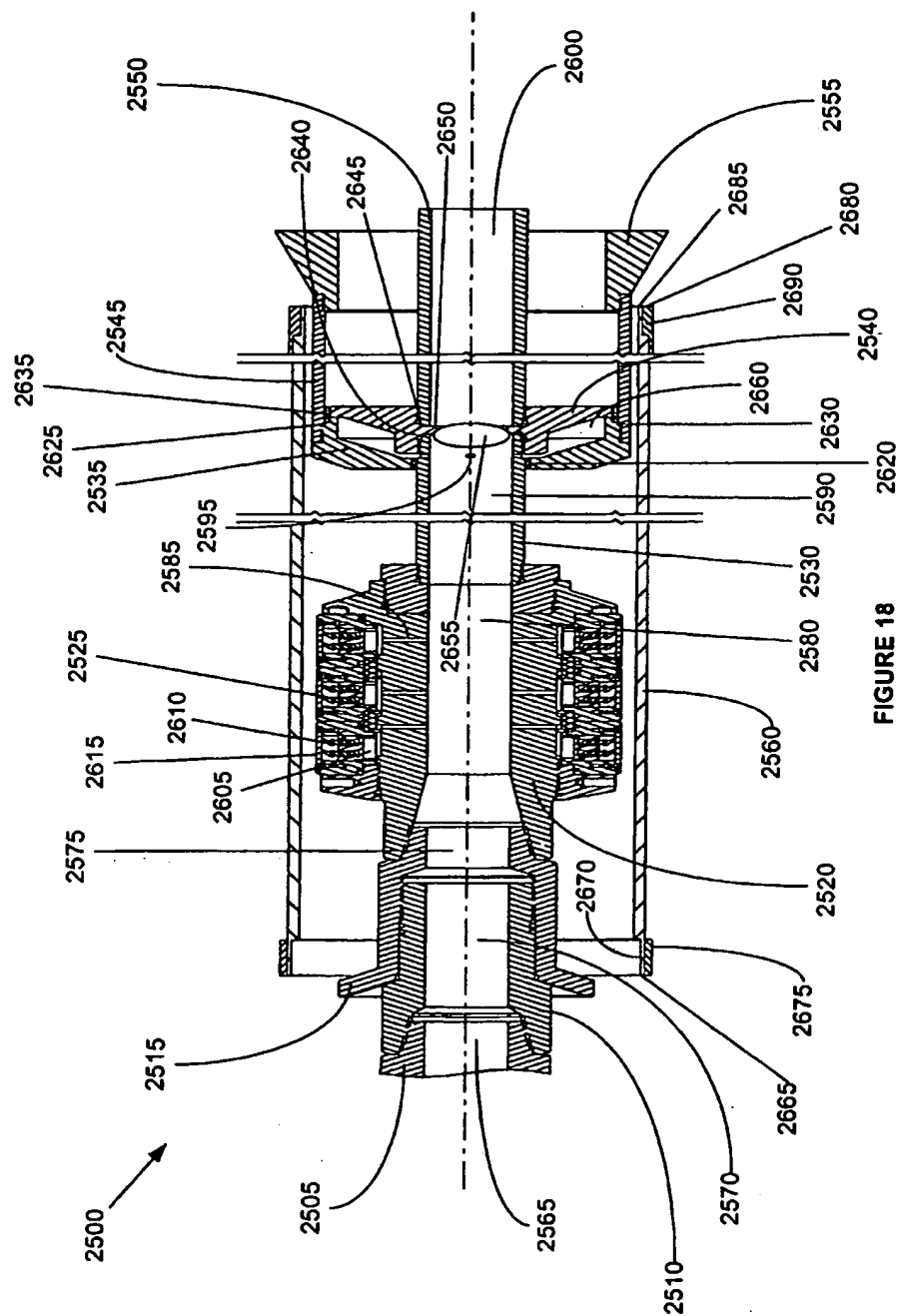
FIGURE 17a

**WO 01/04535**

41/83

**PCT/US00/18635**



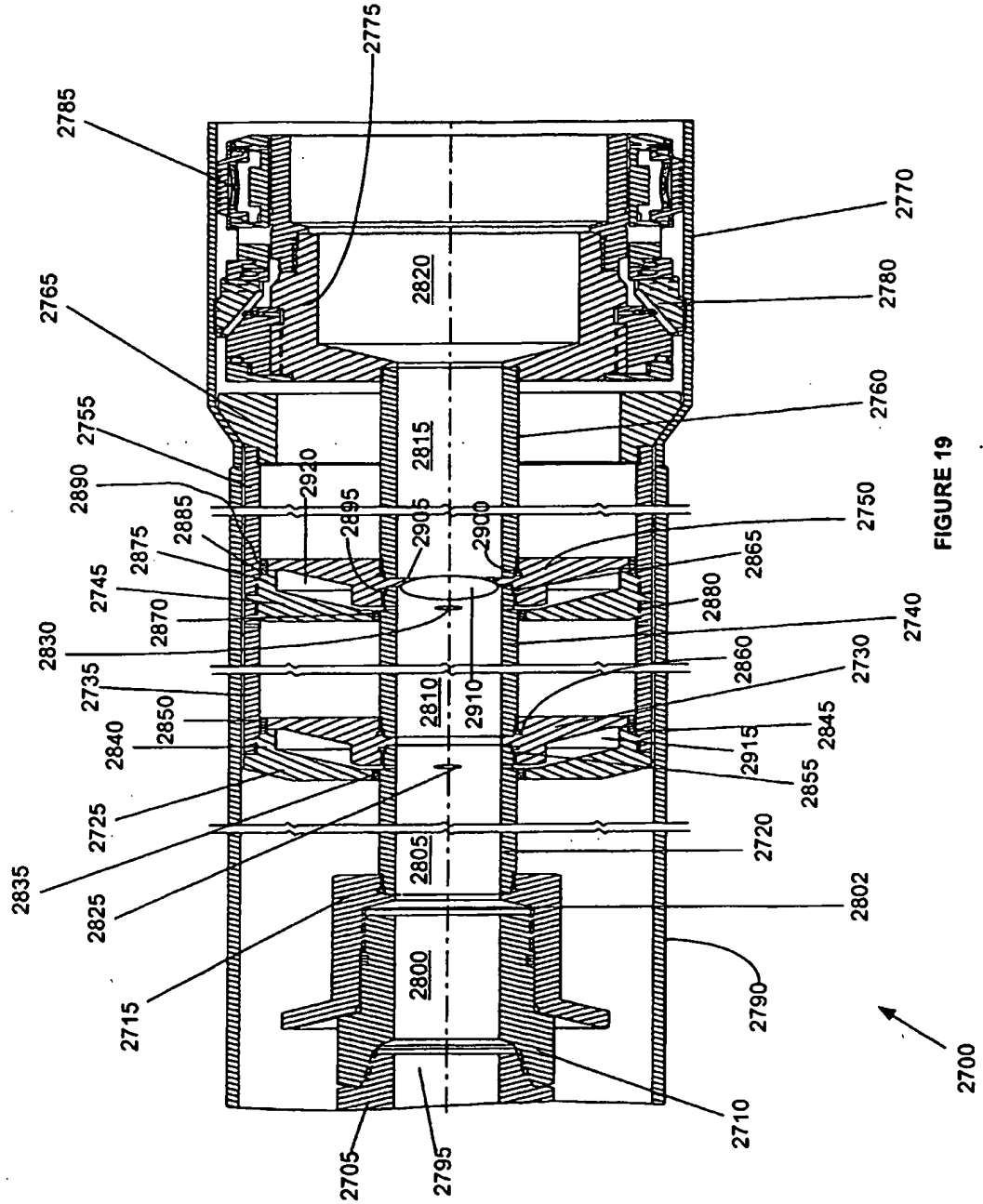


**FIGURE 18**

WO 01/04535

43/83

PCT/US00/18635



WO 01/04535

44/83

PCT/US00/18635

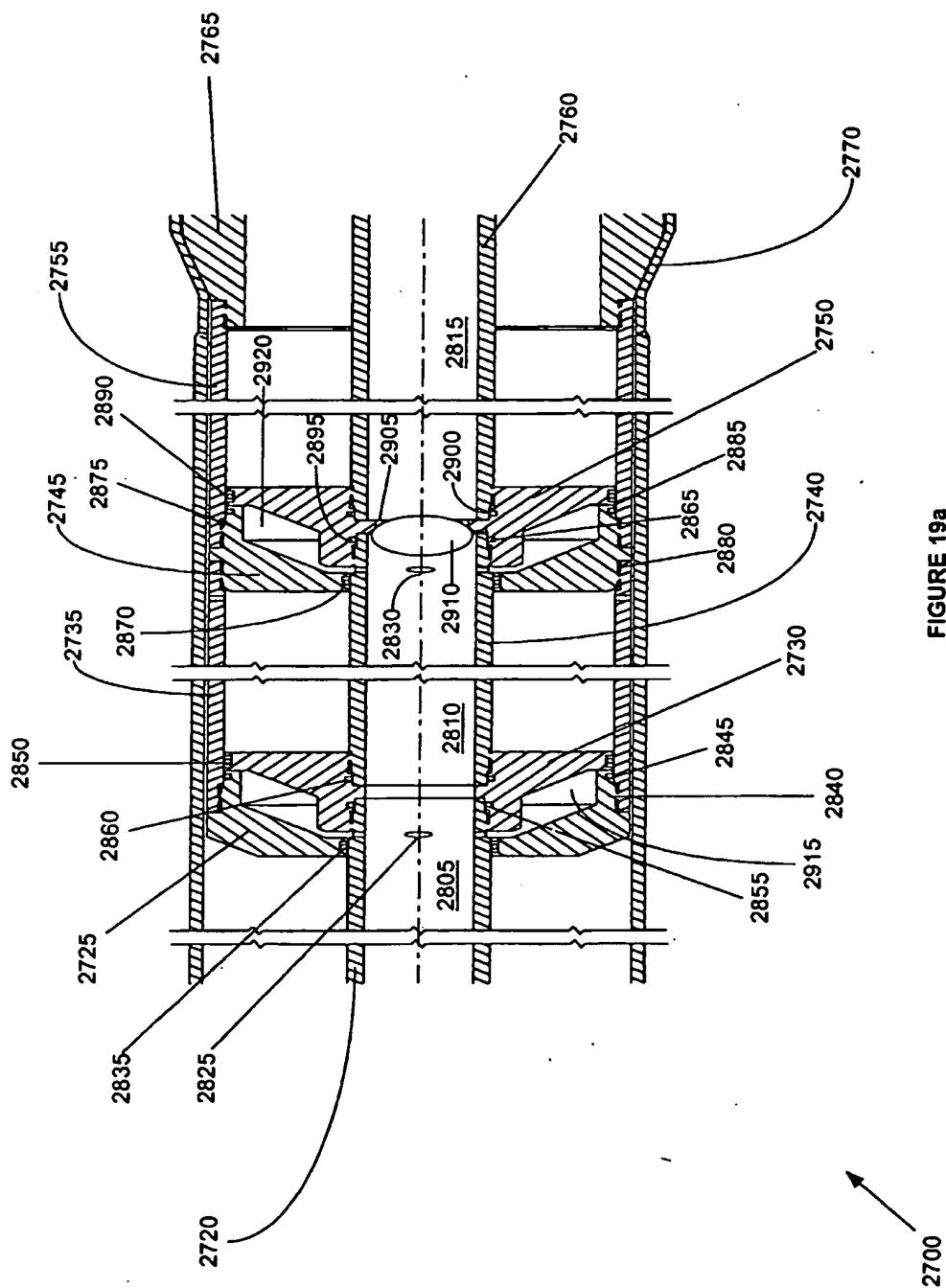


FIGURE 19a

WO 01/04535

45/83

PCT/US00/18635

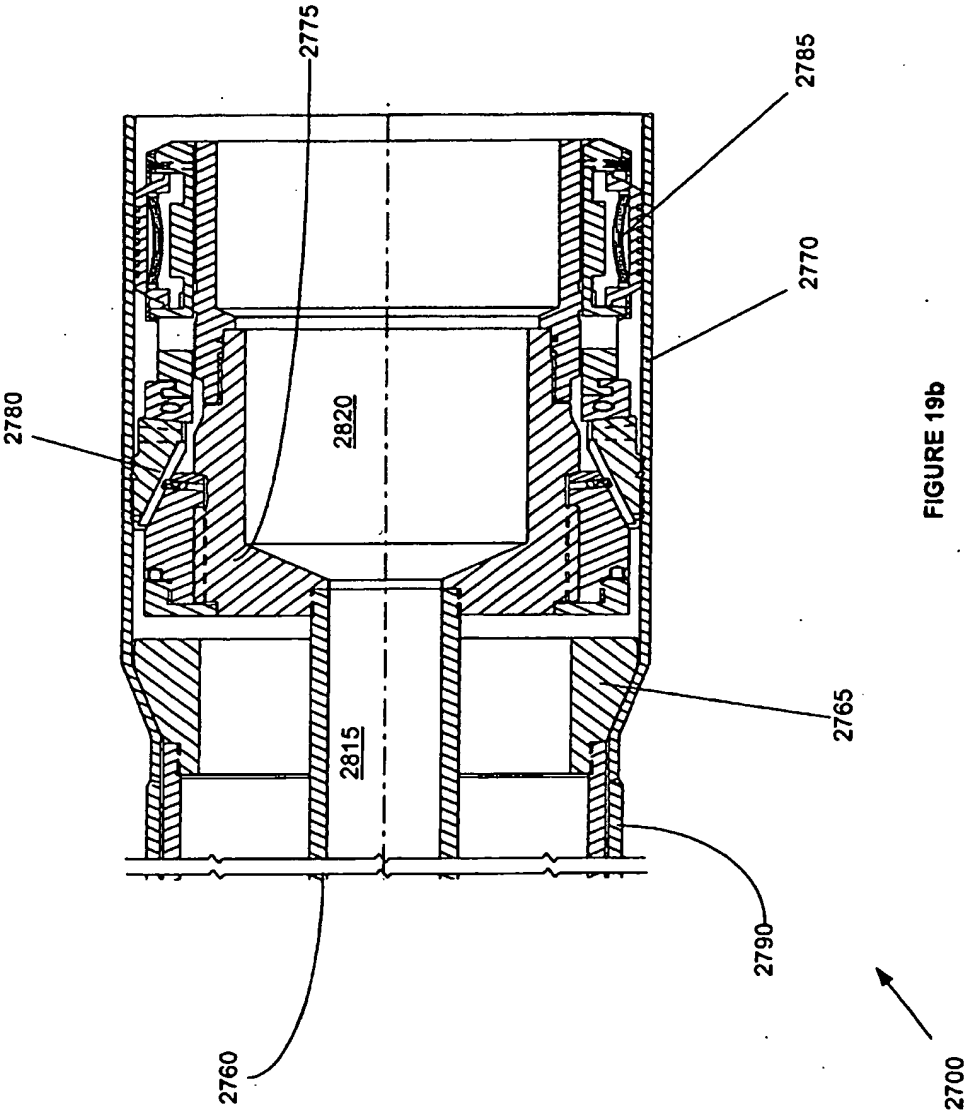
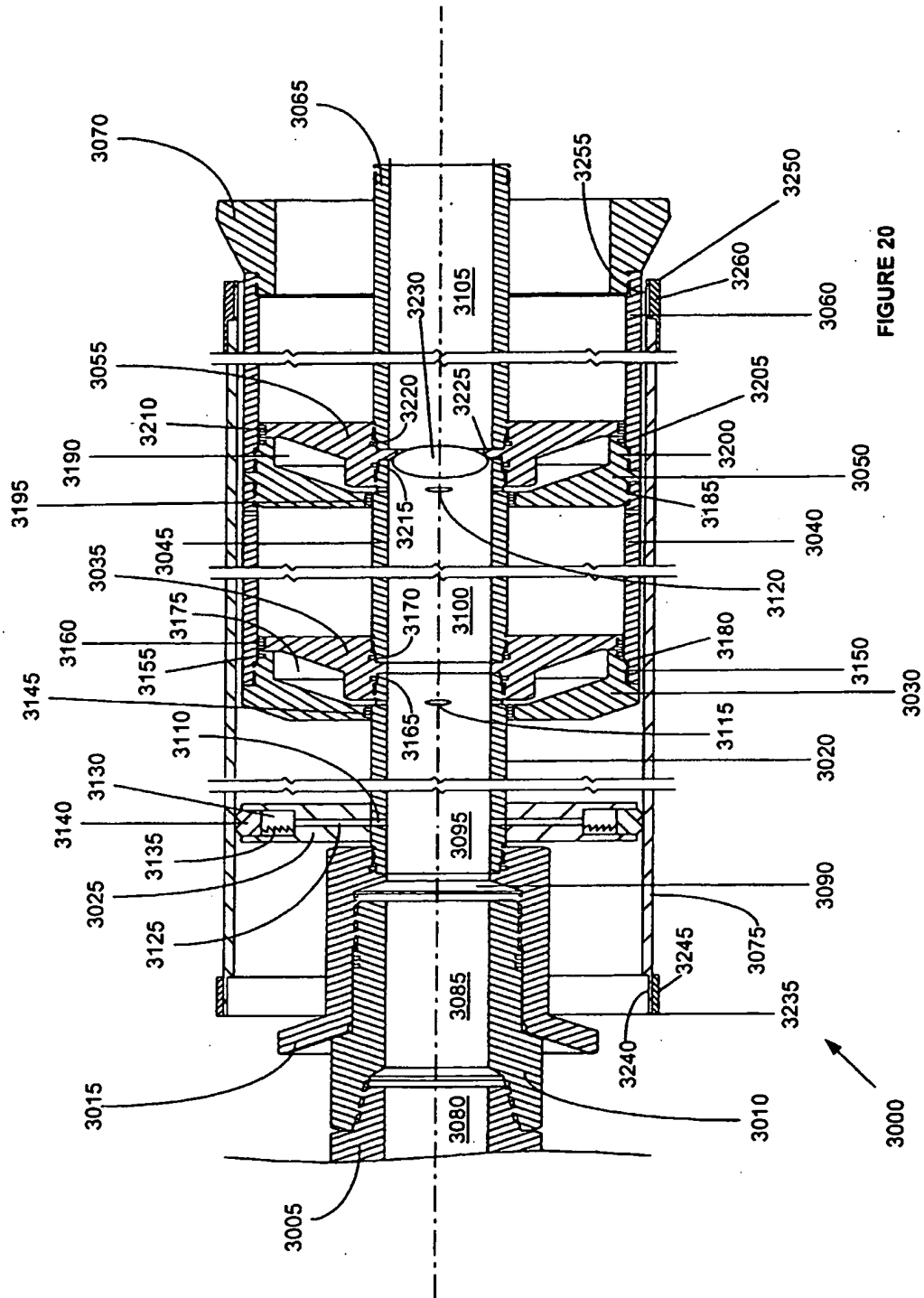


FIGURE 19b



WO 01/04535

PCT/US00/18635



WO 01/04535

PCT/US00/18635

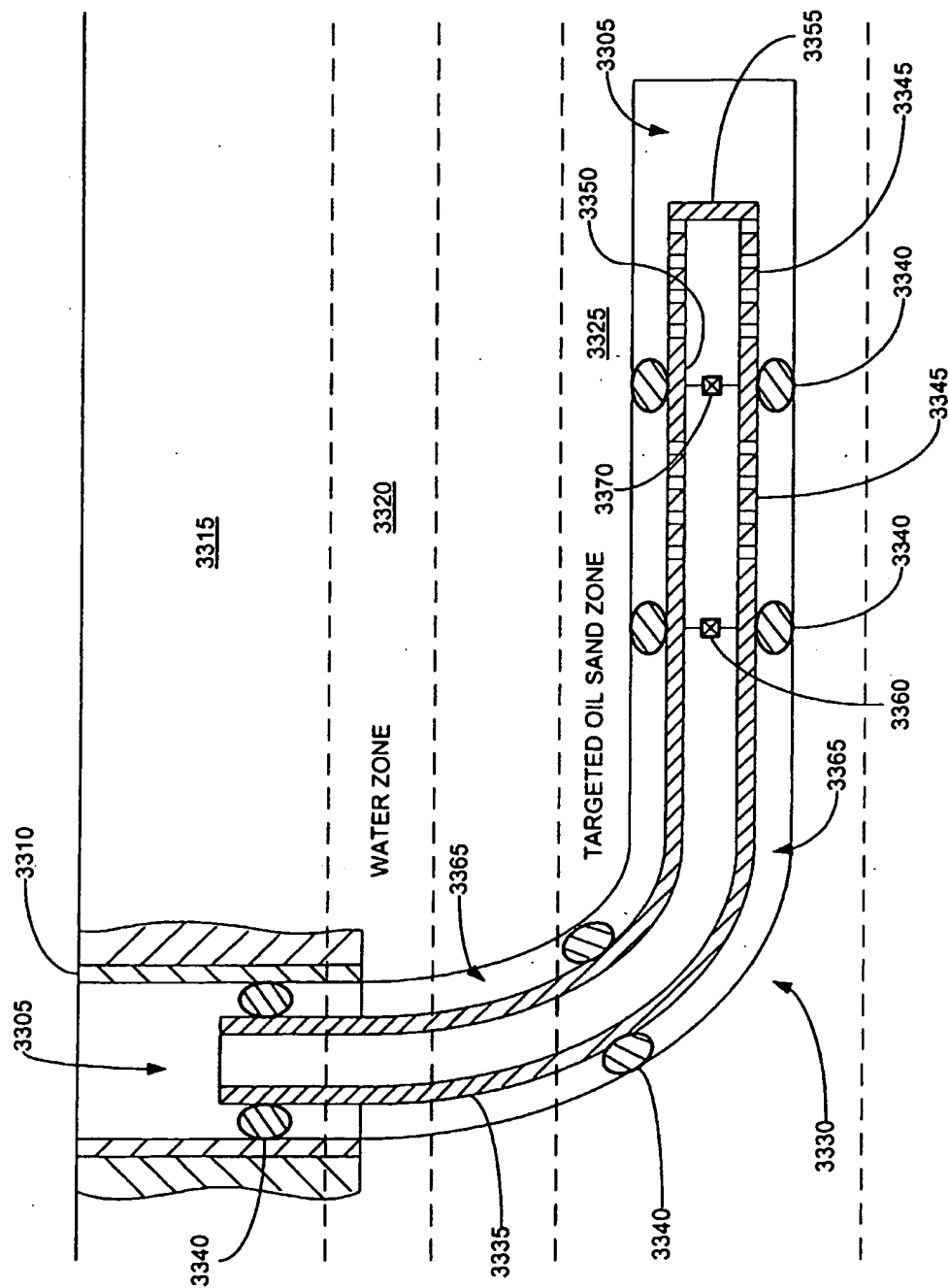


FIGURE 21



WO 01/04535

PCT/US00/18635

49/83

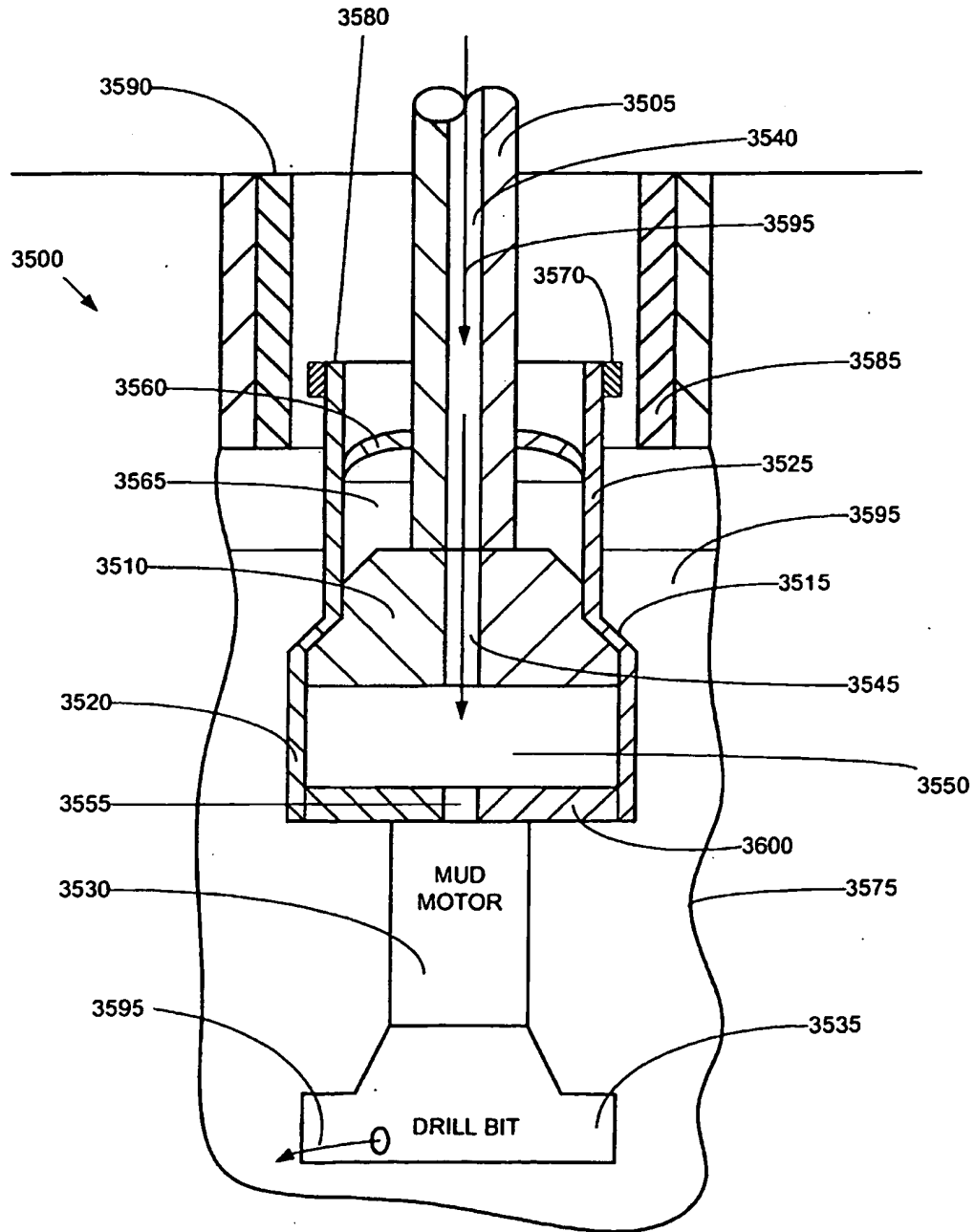


FIGURE 22B

WO 01/04535

PCT/US00/18635

50/83

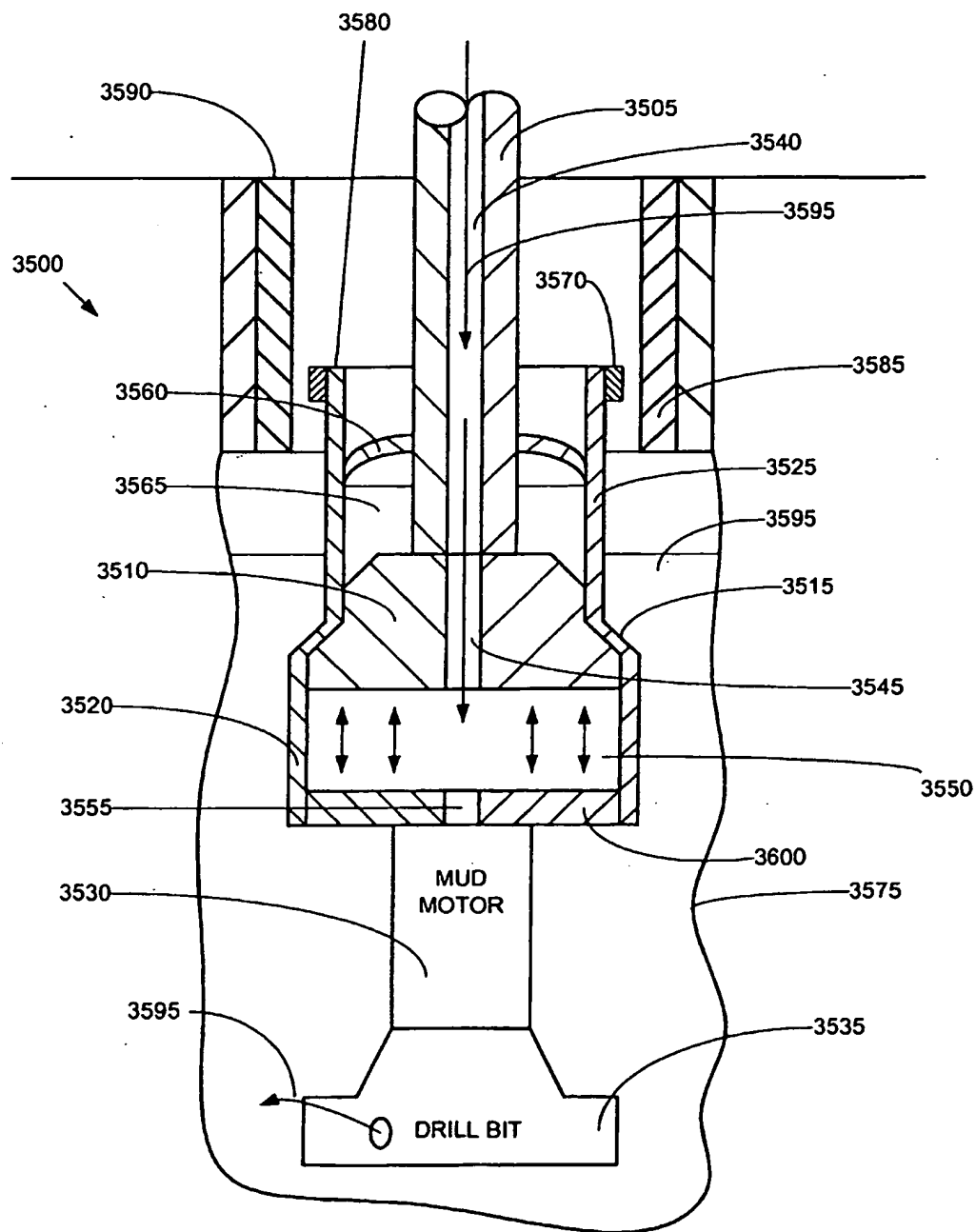
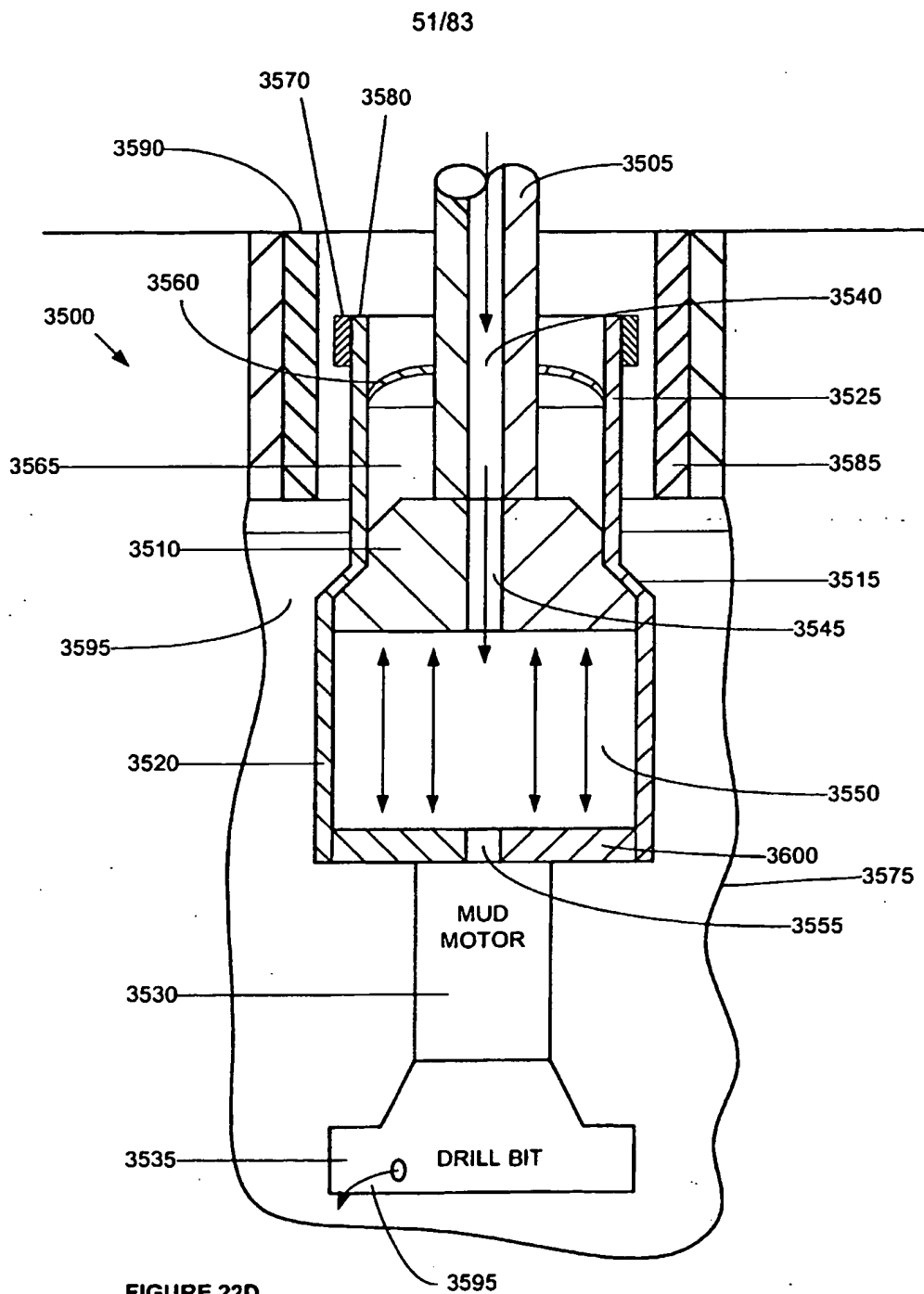


FIGURE 22C

WO 01/04535

PCT/US00/18635



WO 01/04535

PCT/US00/18635

52/83

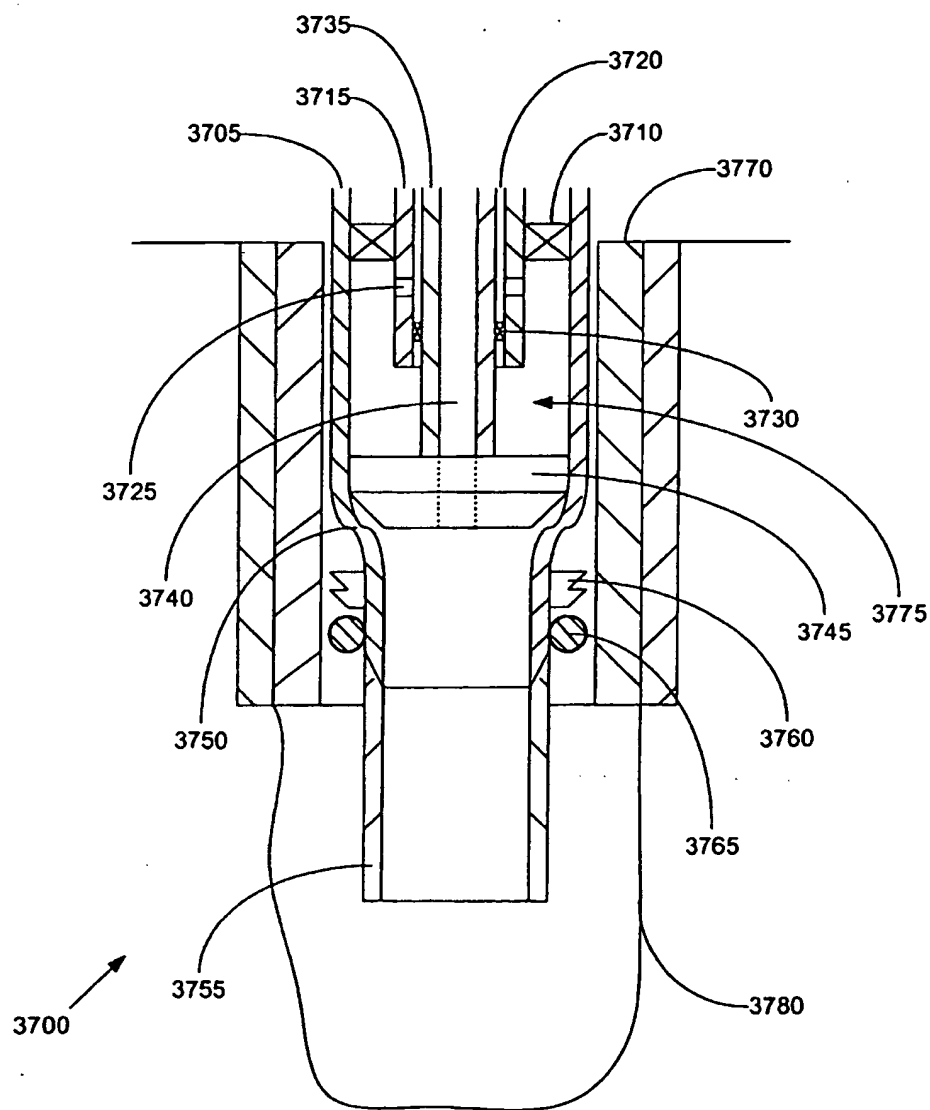


FIGURE 23A

WO 01/04535

PCT/US00/18635

53/83

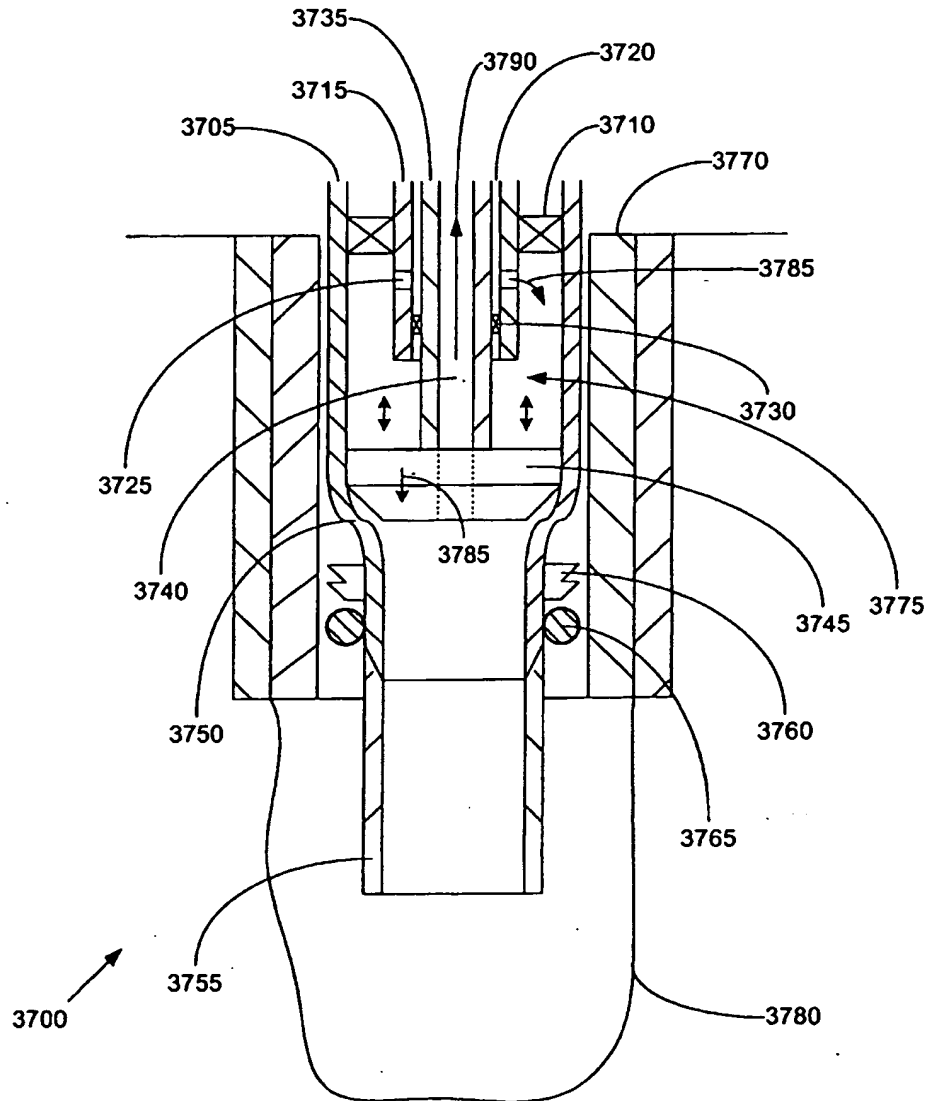


FIGURE 23B



WO 01/04535

PCT/US00/18635

54/83

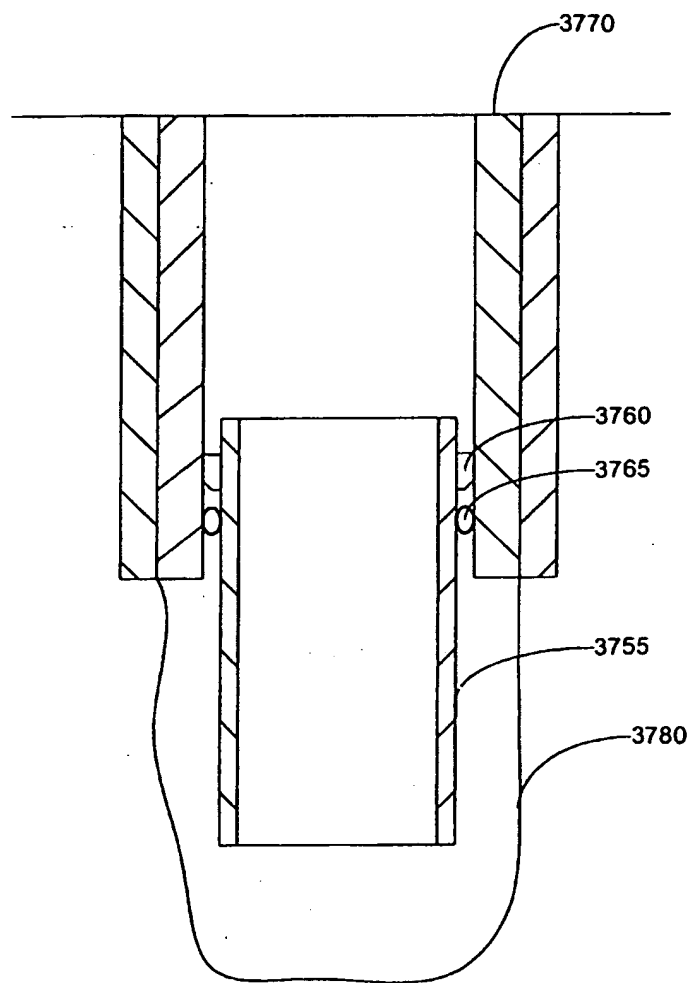
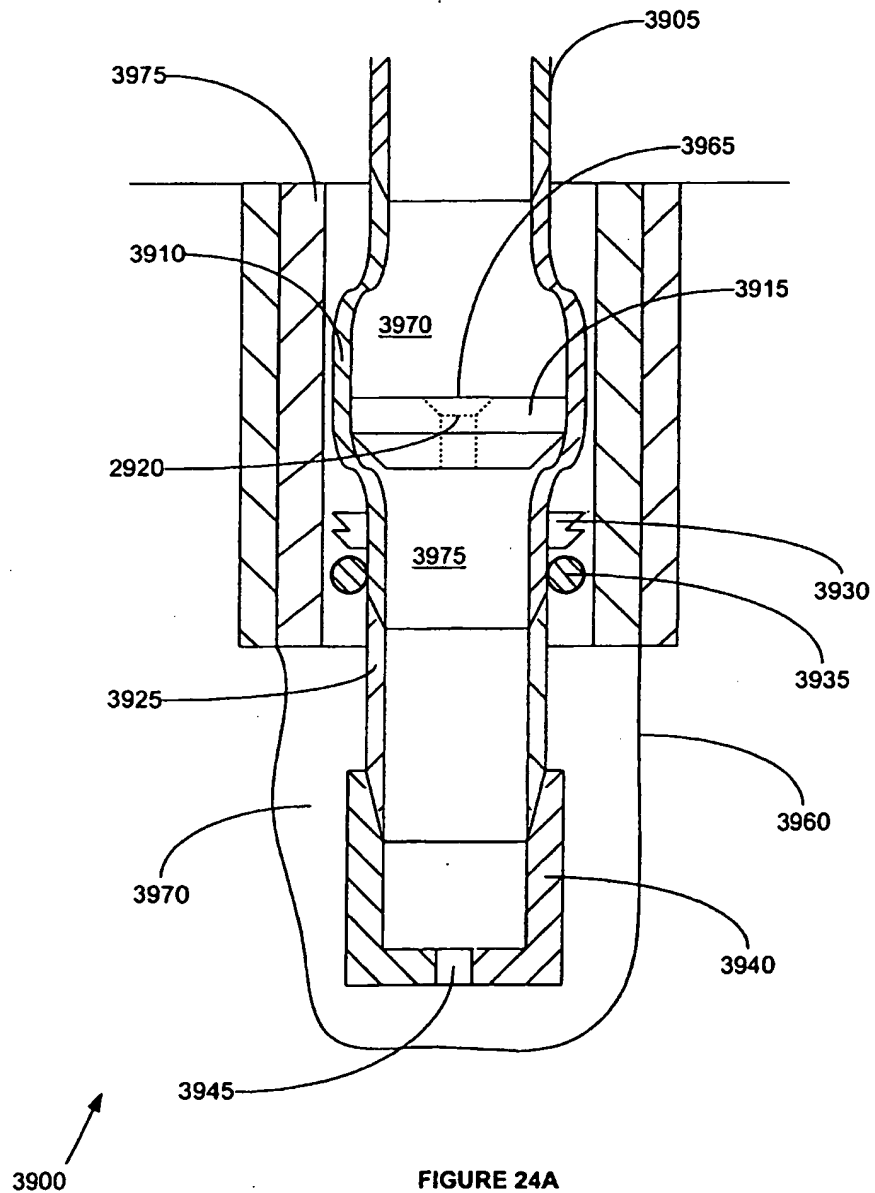


FIGURE 23C

WO 01/04535

PCT/US00/18635

55/83



WO 01/04535

PCT/US00/18635

56/83

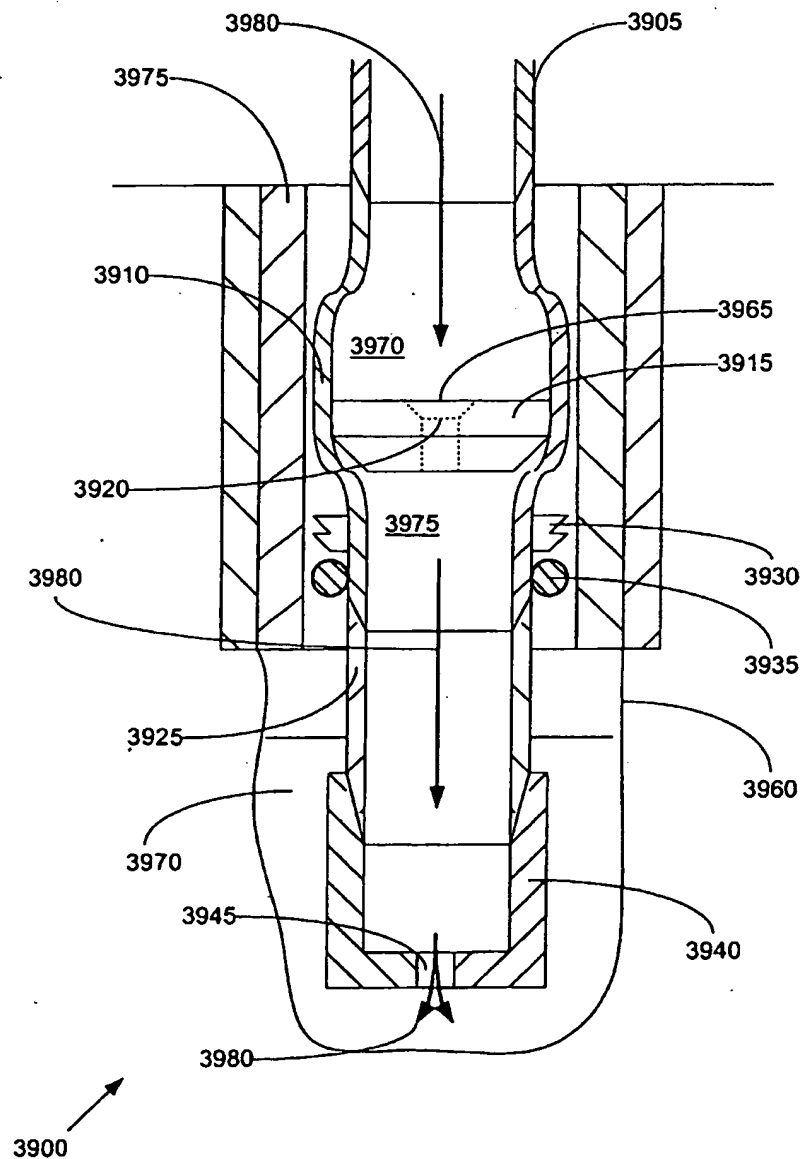


FIGURE 24B

WO 01/04535

PCT/US00/18635

57/83

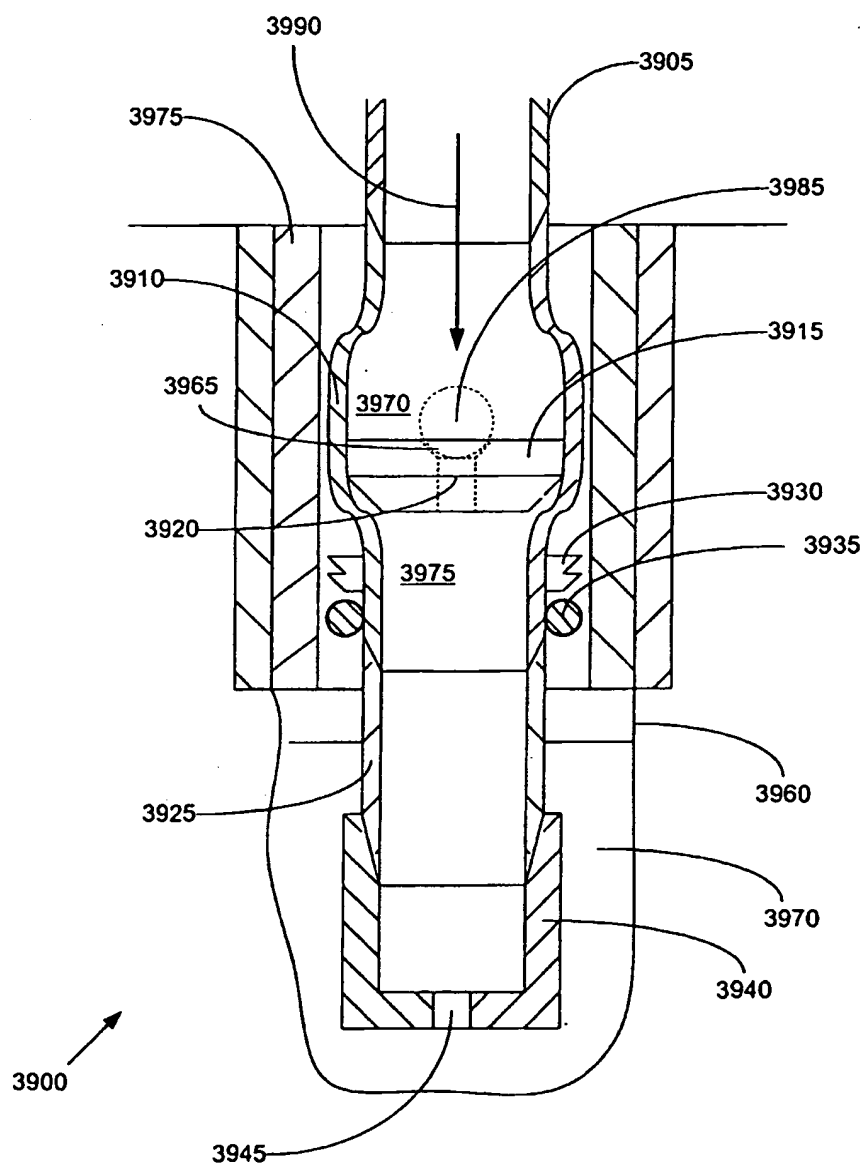


FIGURE 24C

WO 01/04535

PCT/US00/18635

58/83

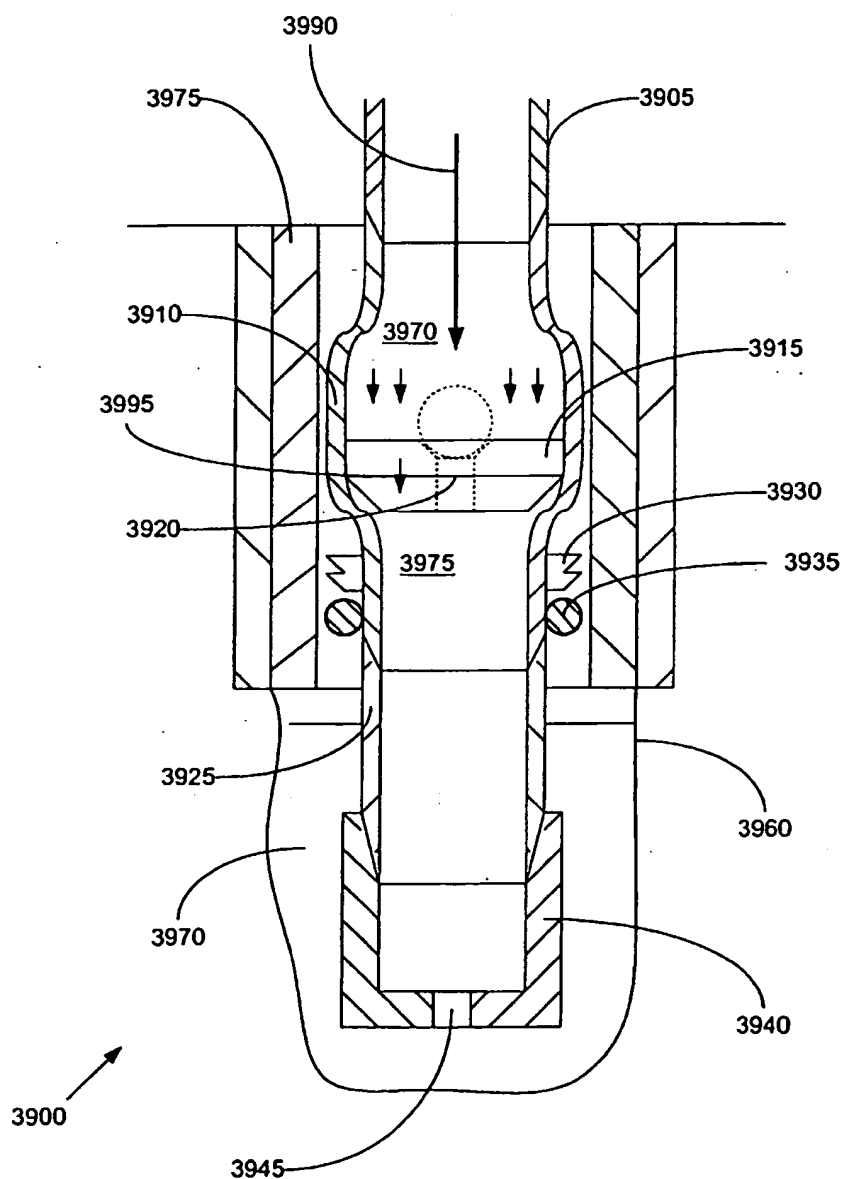


FIGURE 24D

WO 01/04535

PCT/US00/18635

59/83

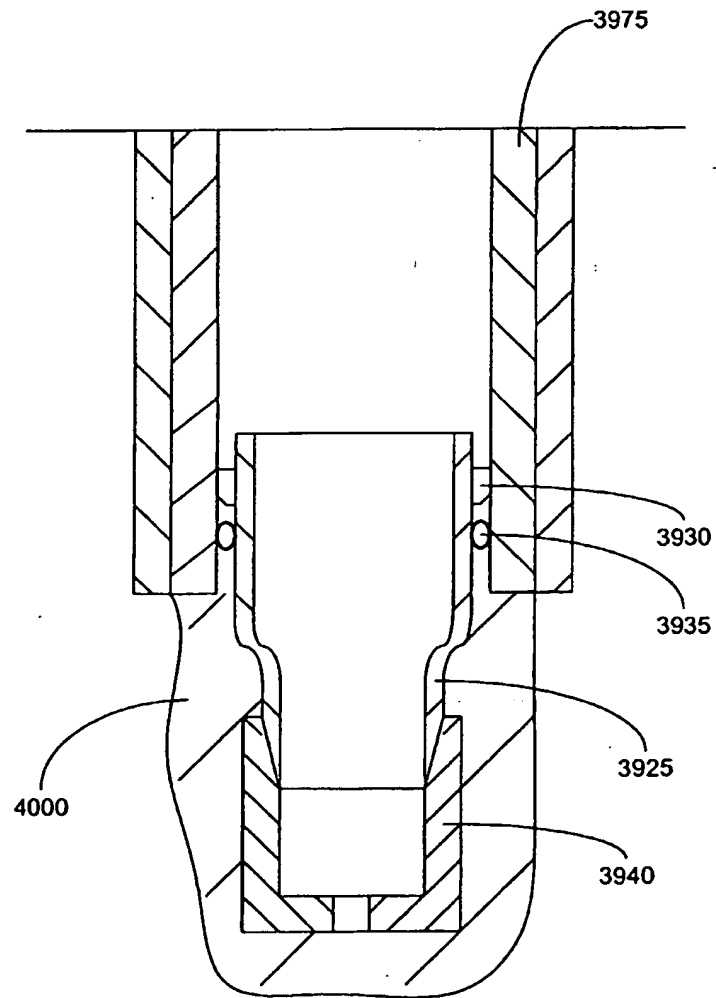


FIGURE 24E

WO 01/04535

PCT/US00/18635

60/83

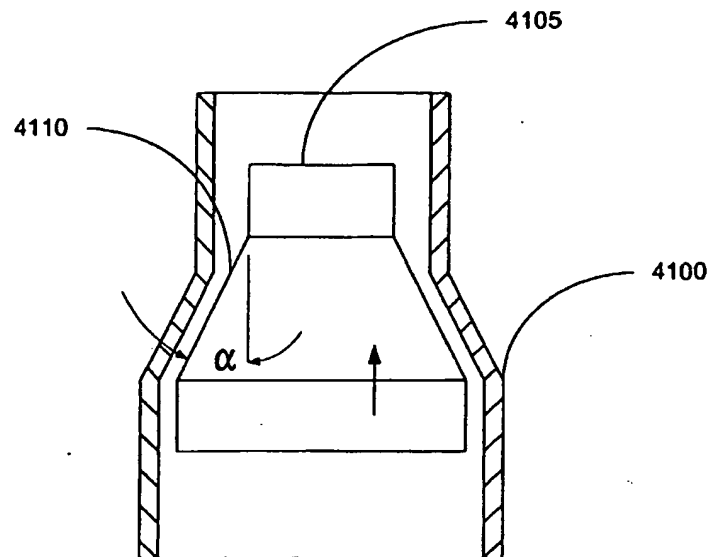


FIGURE 25

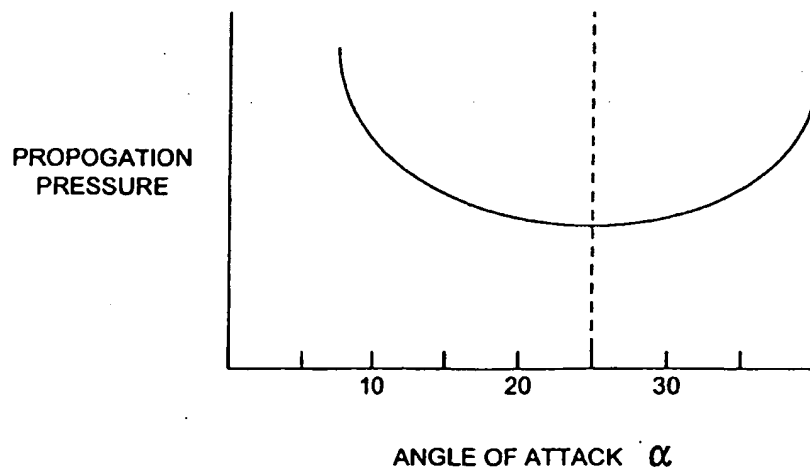
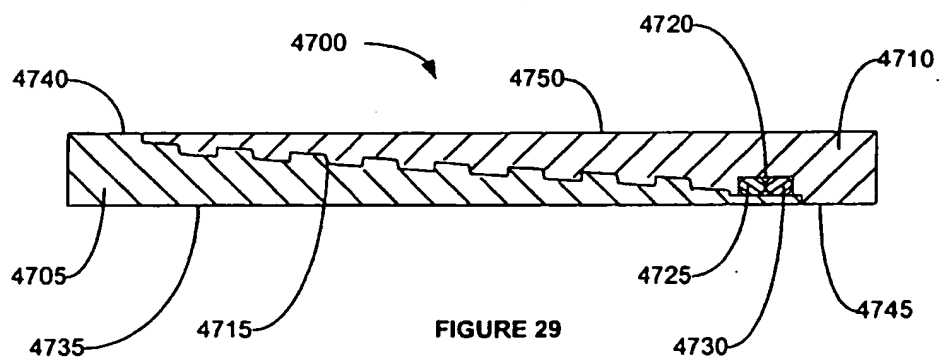
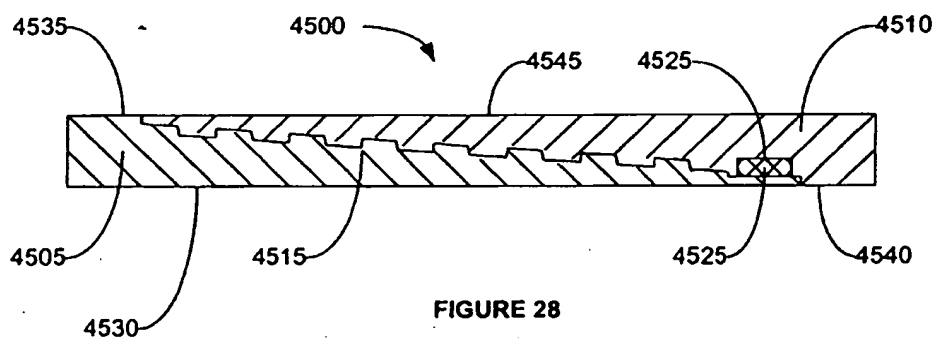
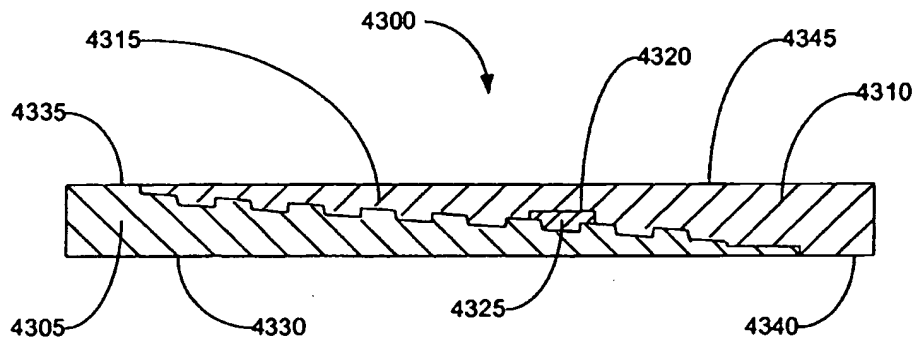


FIGURE 26

WO 01/04535

PCT/US00/18635

61/83

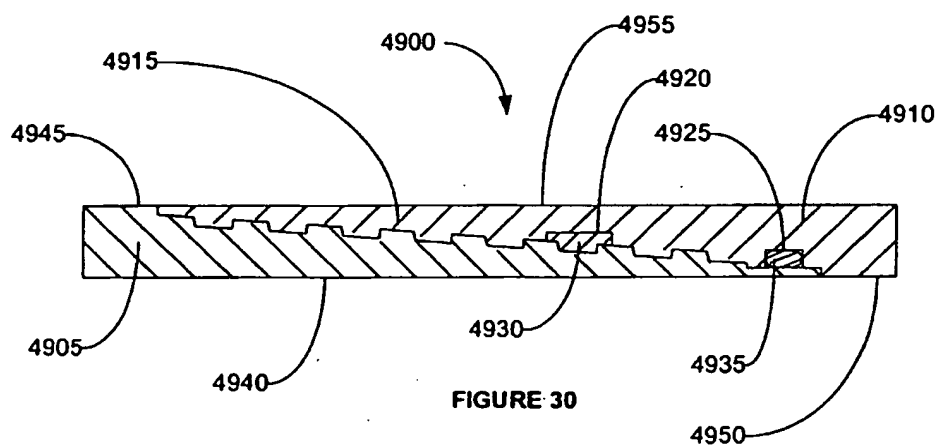




WO 01/04535

PCT/US00/18635

62/83



WO 01/04535

63/83

PCT/US00/18635

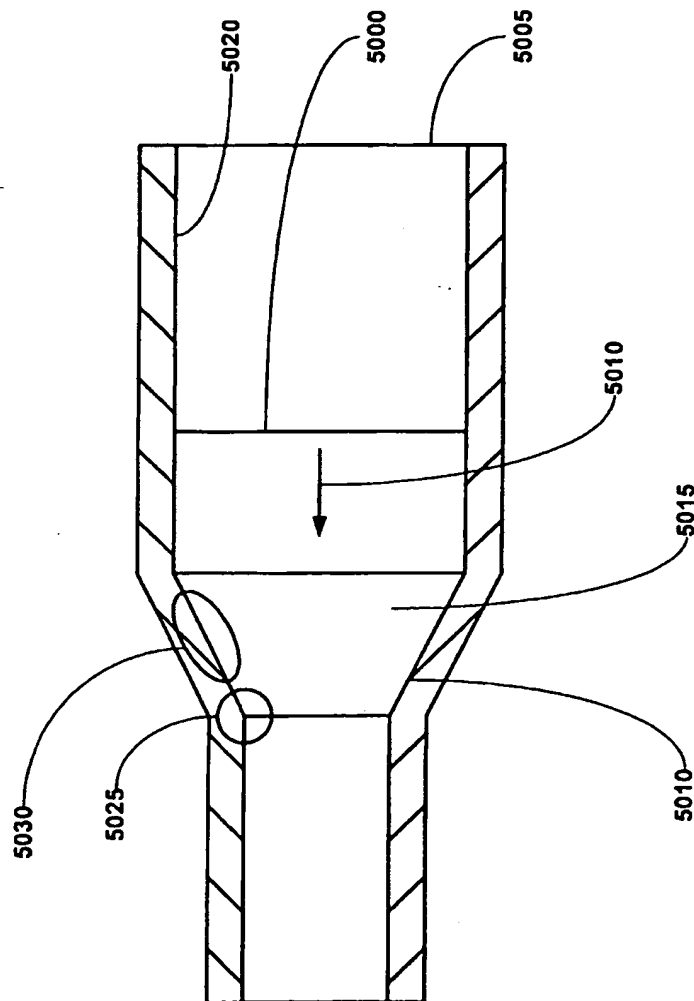


FIGURE 31

WO 01/04535

64/83

PCT/US00/18635

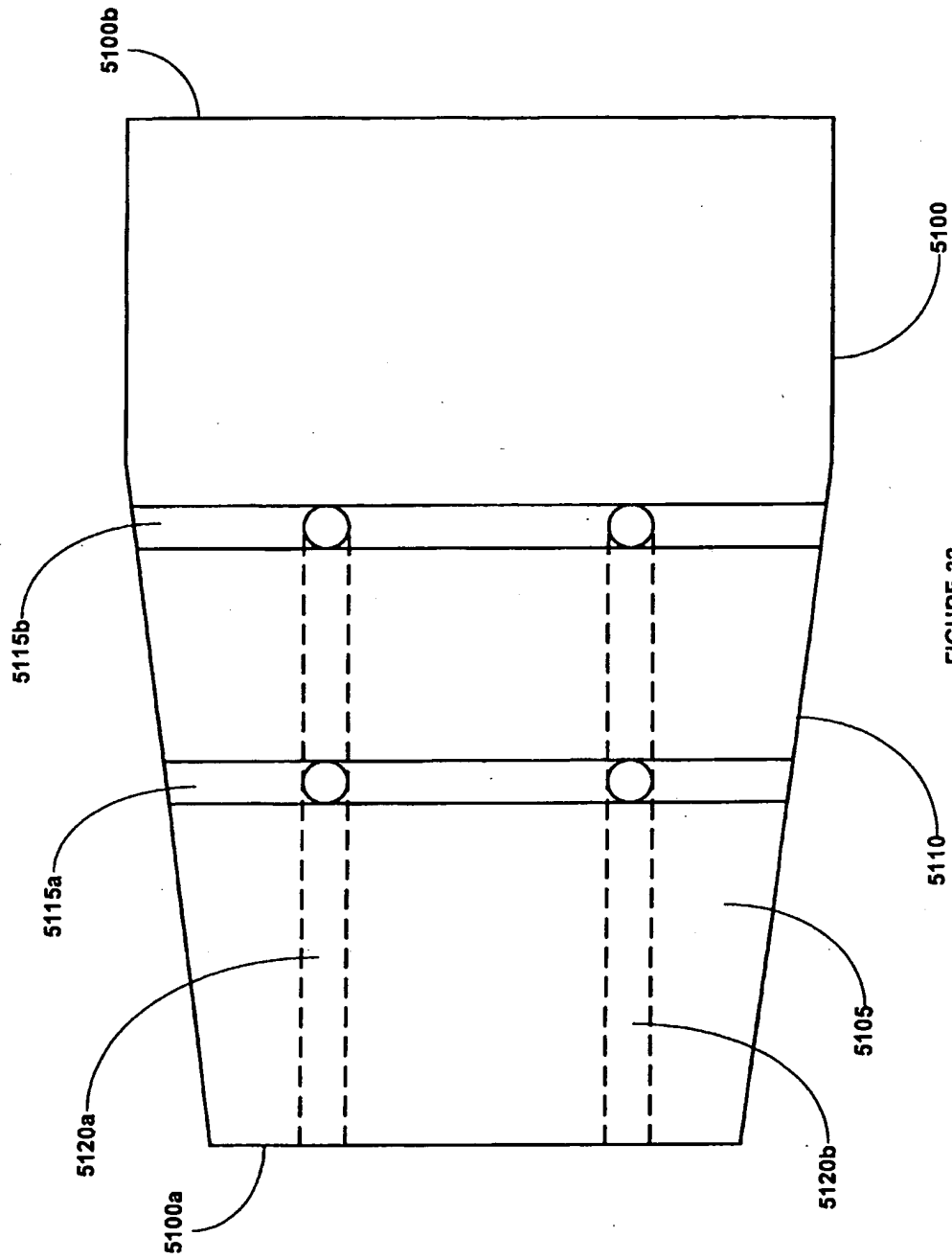


FIGURE 32

WO 01/04535

65/83

PCT/US00/18635

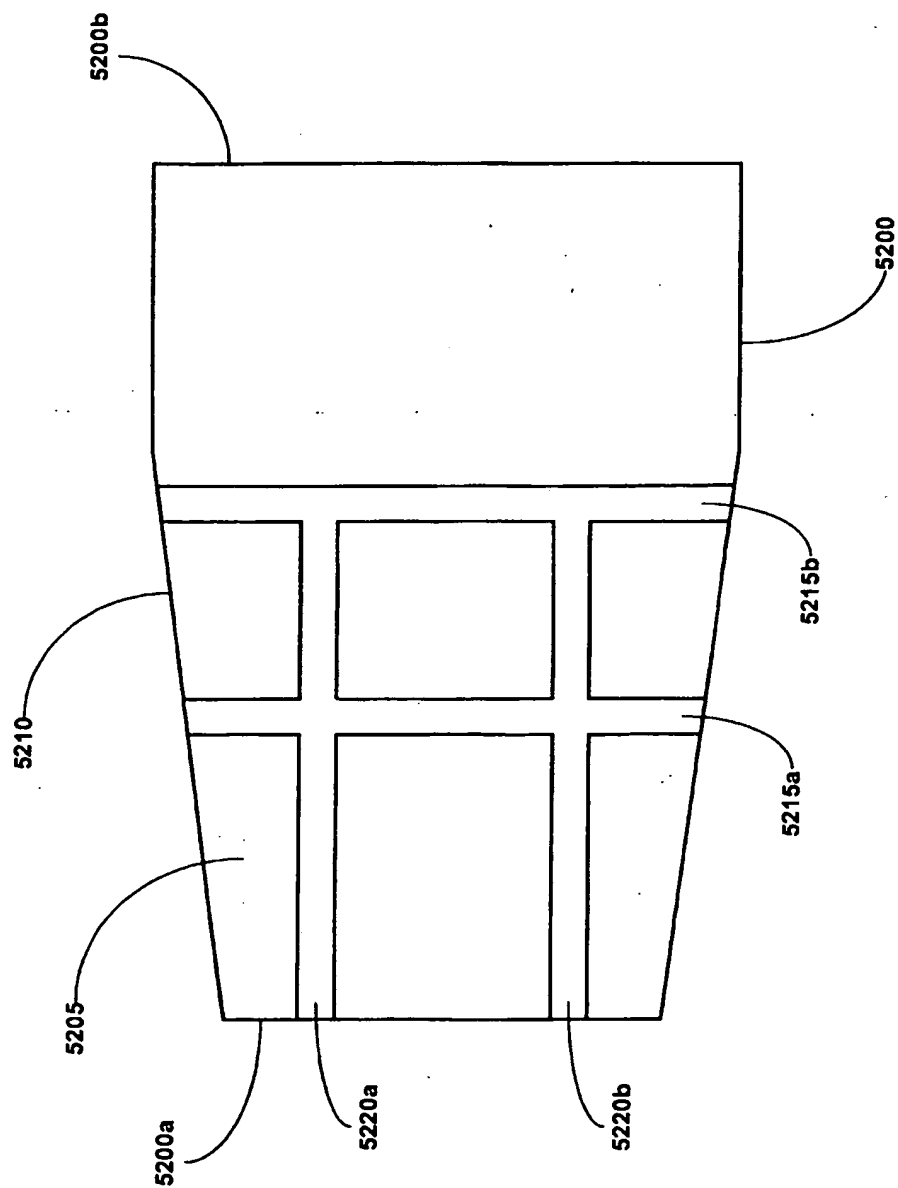


FIGURE 33

WO 01/04535

66/83

PCT/US00/18635

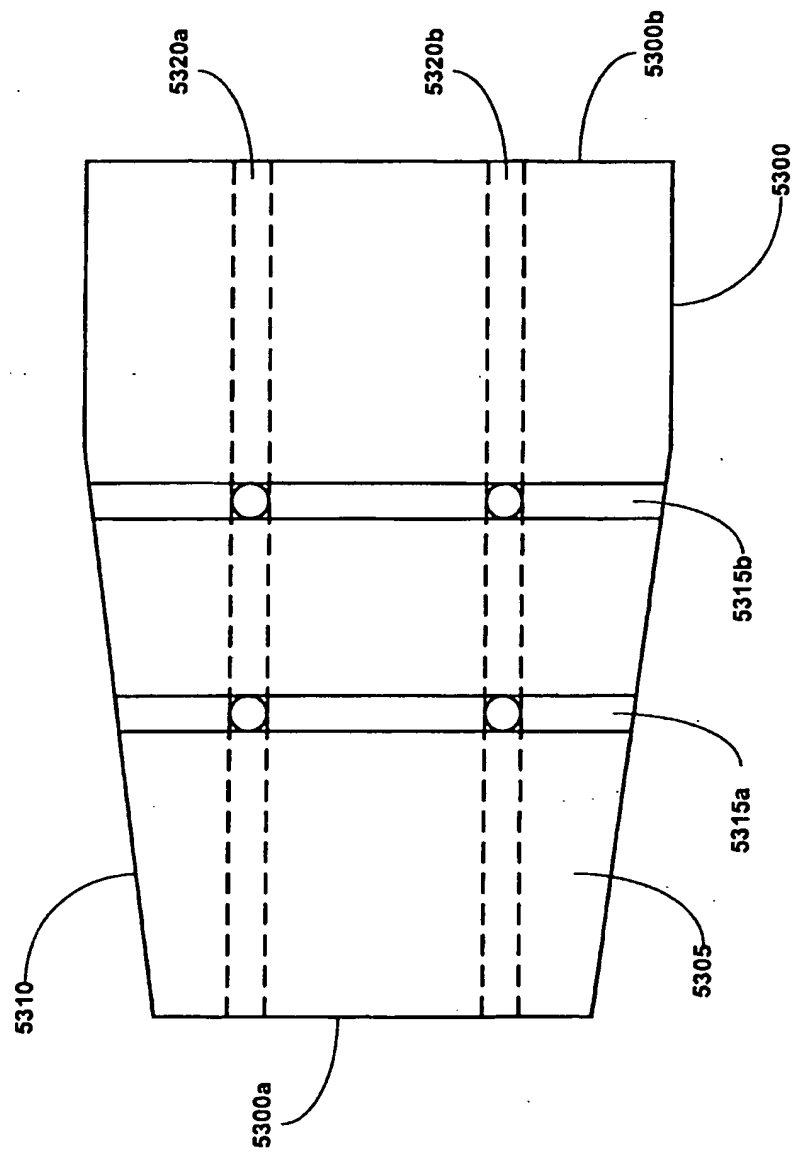


FIGURE 34

WO 01/04535

67/83

PCT/US00/18635

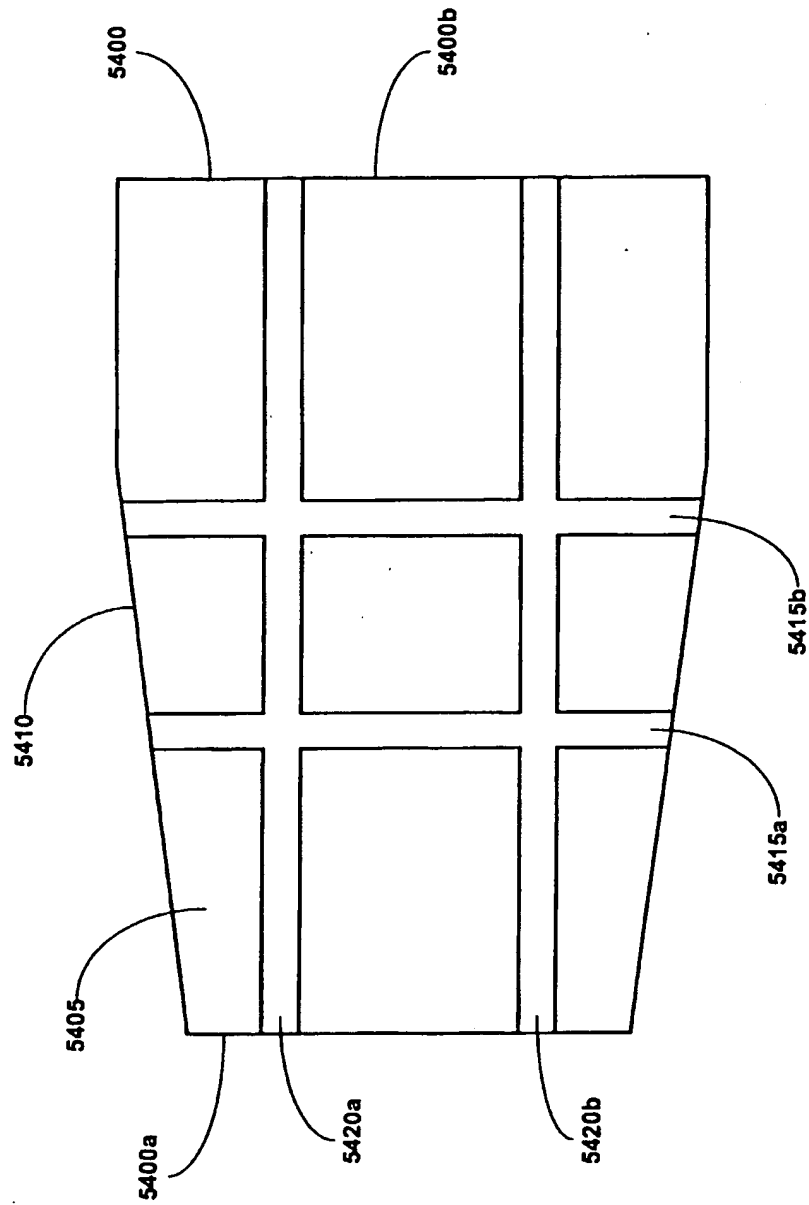


FIGURE 35

WO 01/04535

68/83

PCT/US00/18635

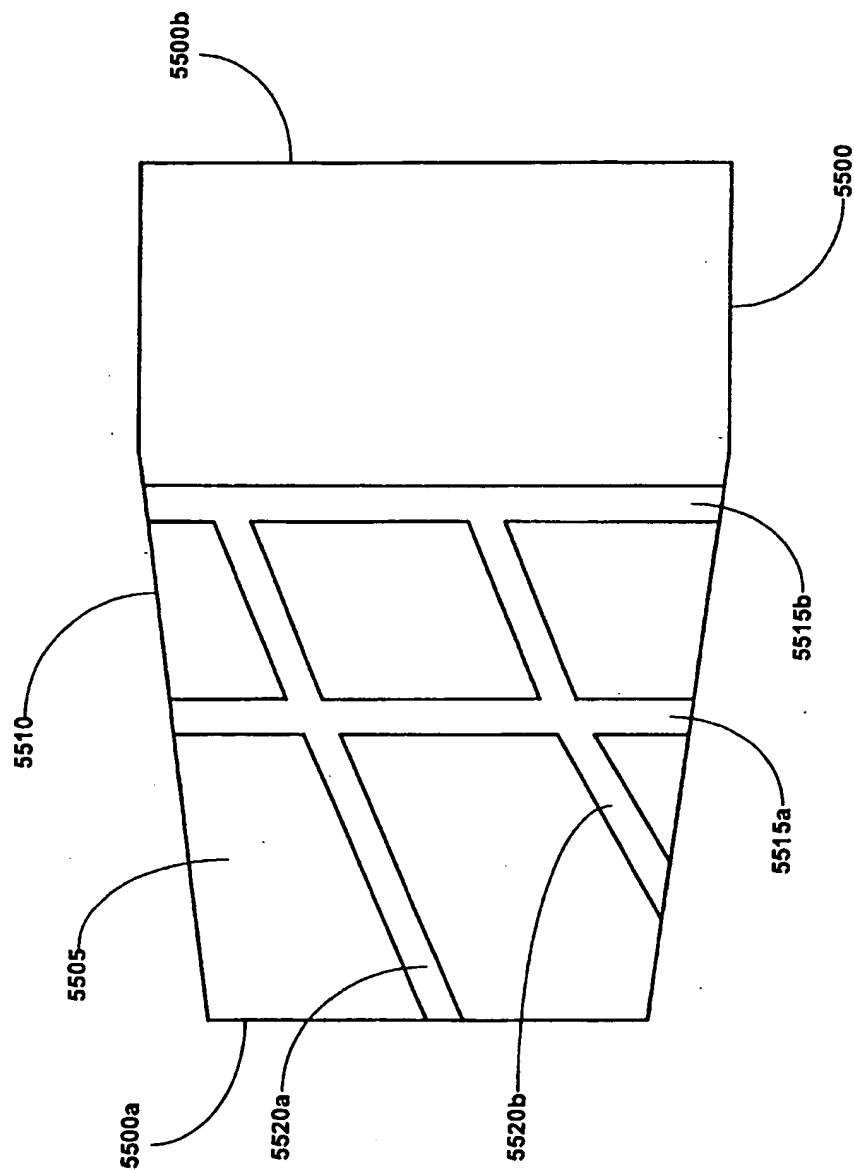


FIGURE 36

WO 01/04535

69/83

PCT/US00/18635

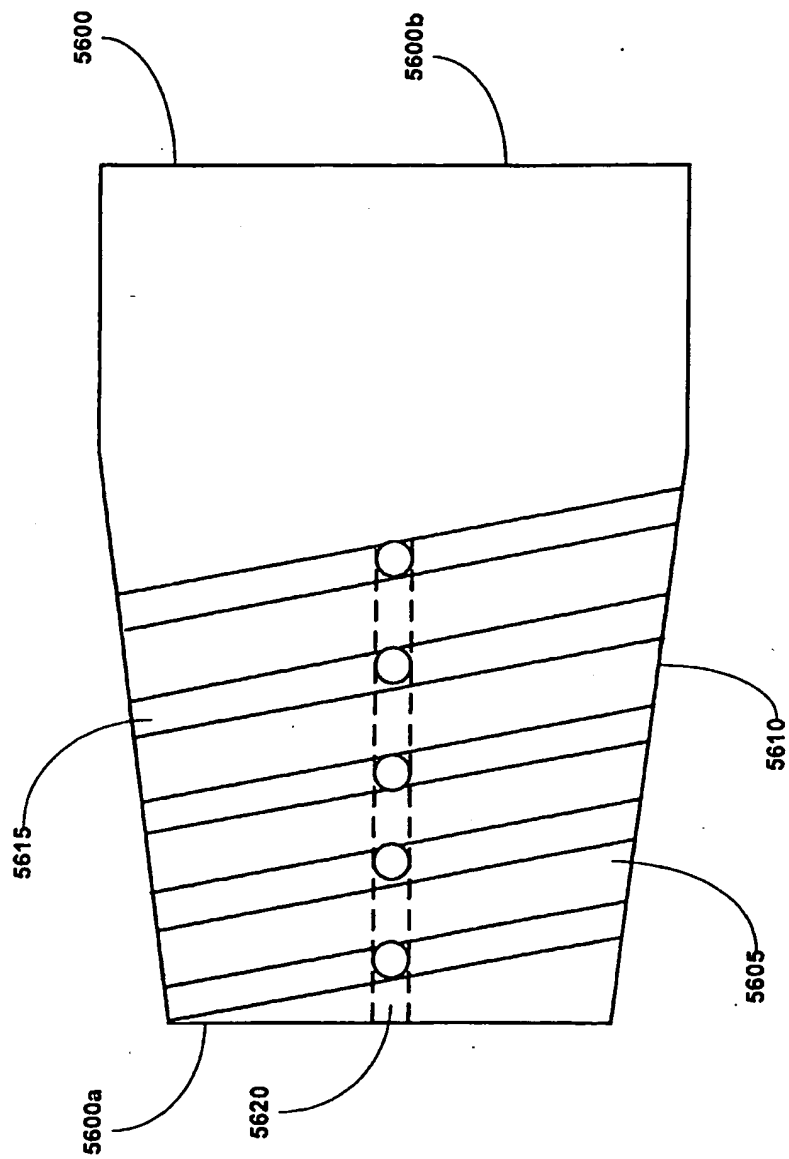


FIGURE 37



WO 01/04535

70/83

PCT/US00/18635

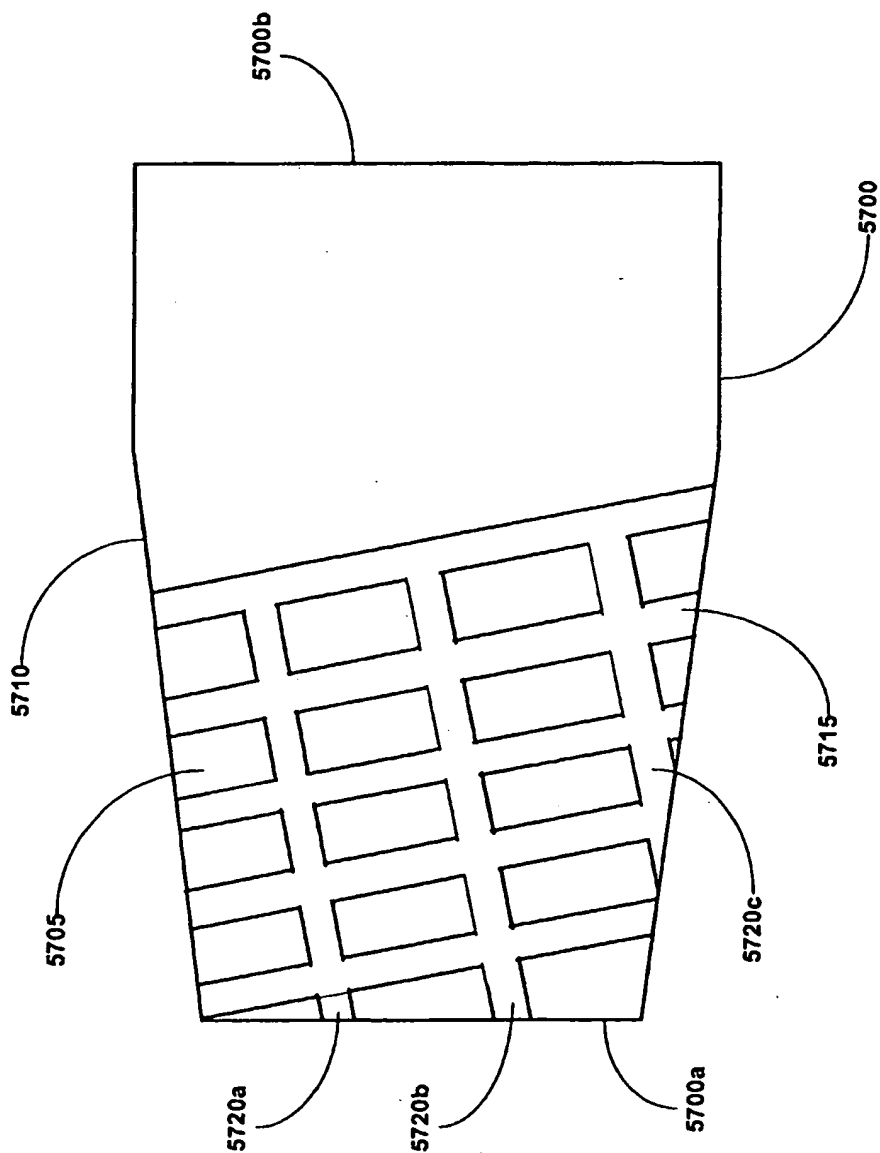


FIGURE 38

WO 01/04535

PCT/US00/18635

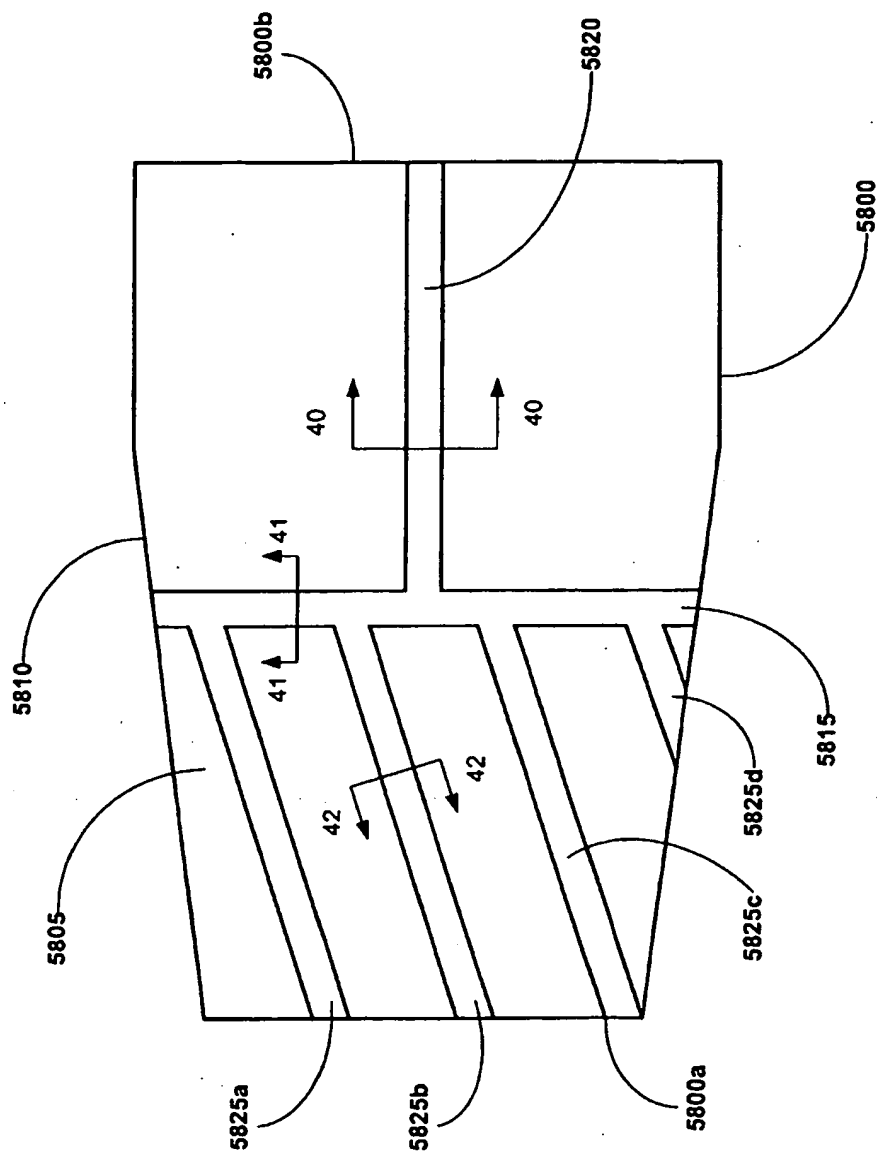


FIGURE 39

WO 01/04535

PCT/US00/18635

72/83

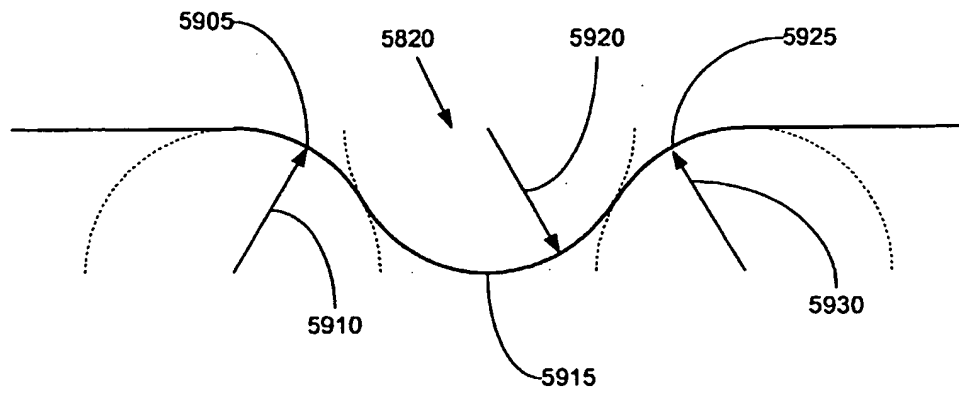


FIGURE 40

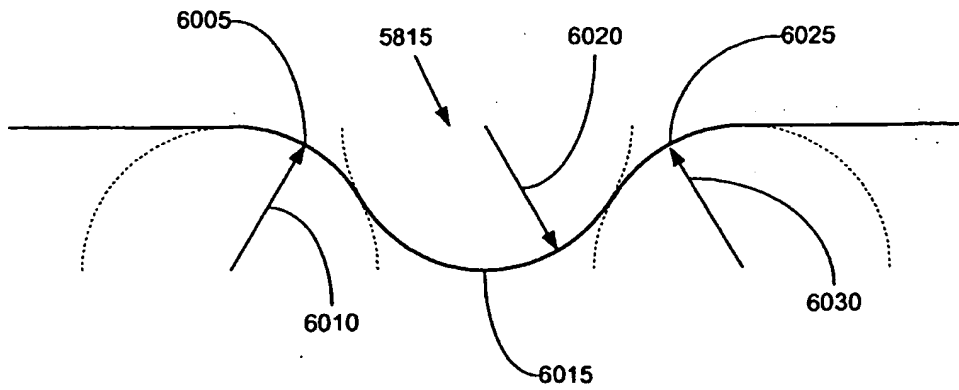


FIGURE 41

WO 01/04535

PCT/US00/18635

73/83

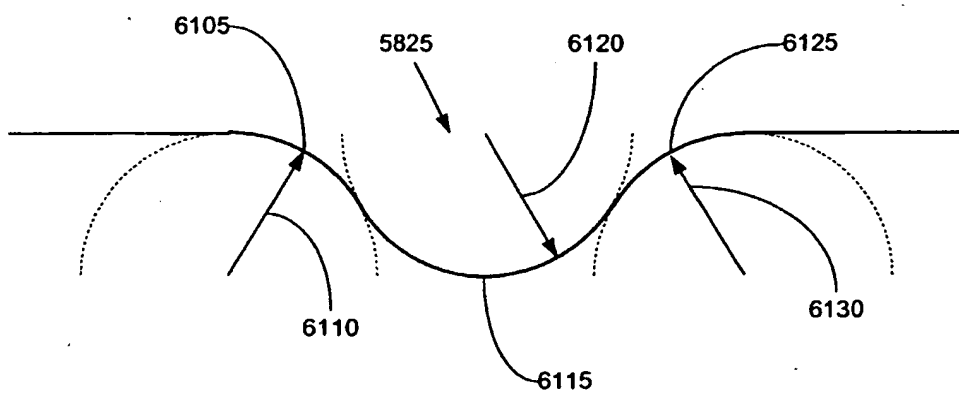


FIGURE 42

WO 01/04535

PCT/US00/18635

74/83

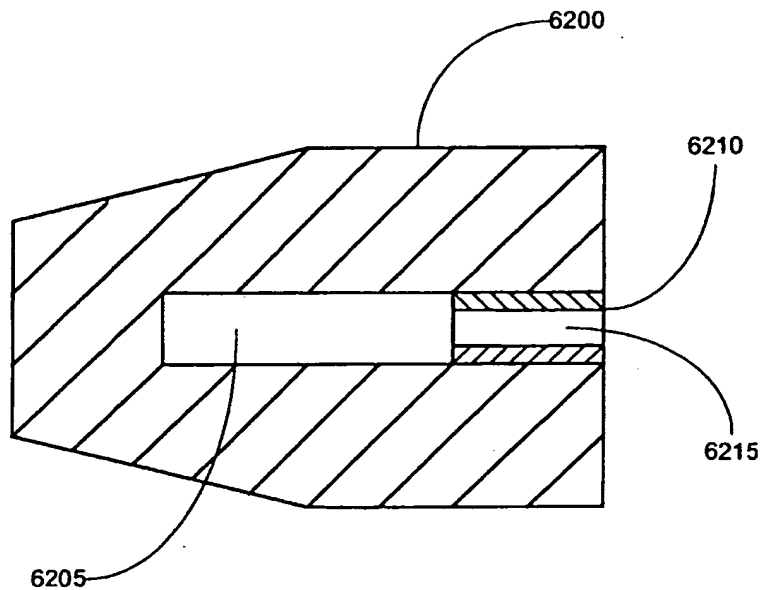


FIGURE 43

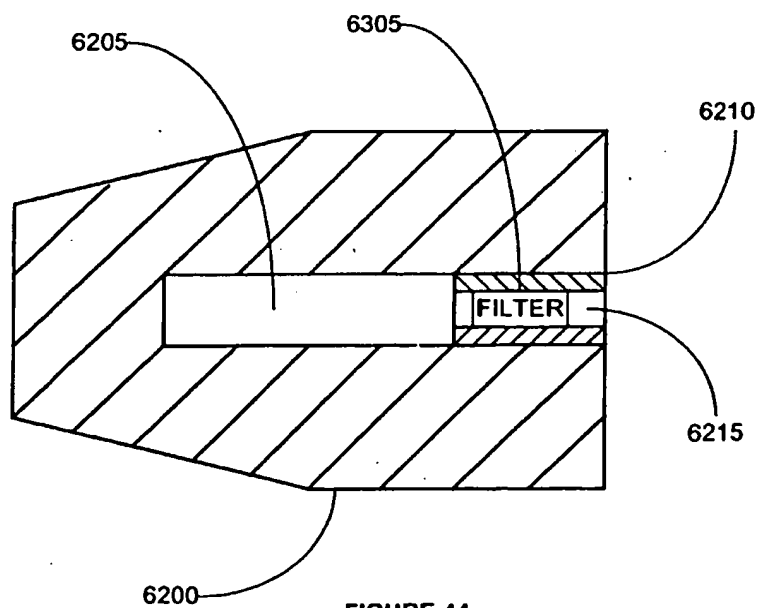


FIGURE 44

WO 01/04535

PCT/US00/18635

75/83

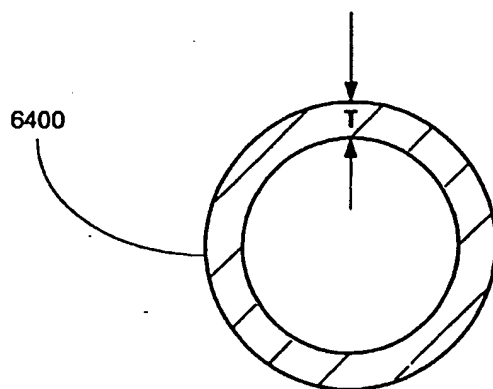


FIGURE 45

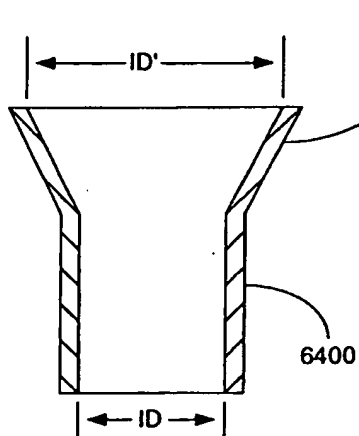


FIGURE 46

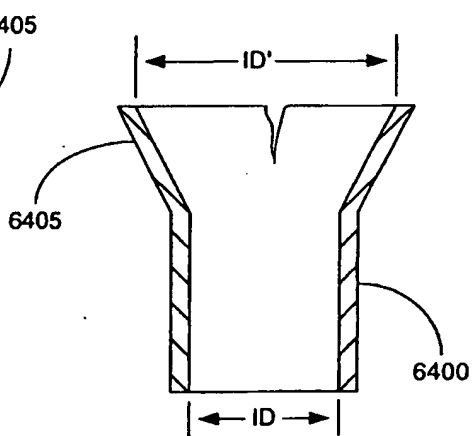


FIGURE 47

WO 01/04535

PCT/US00/18635

76/83

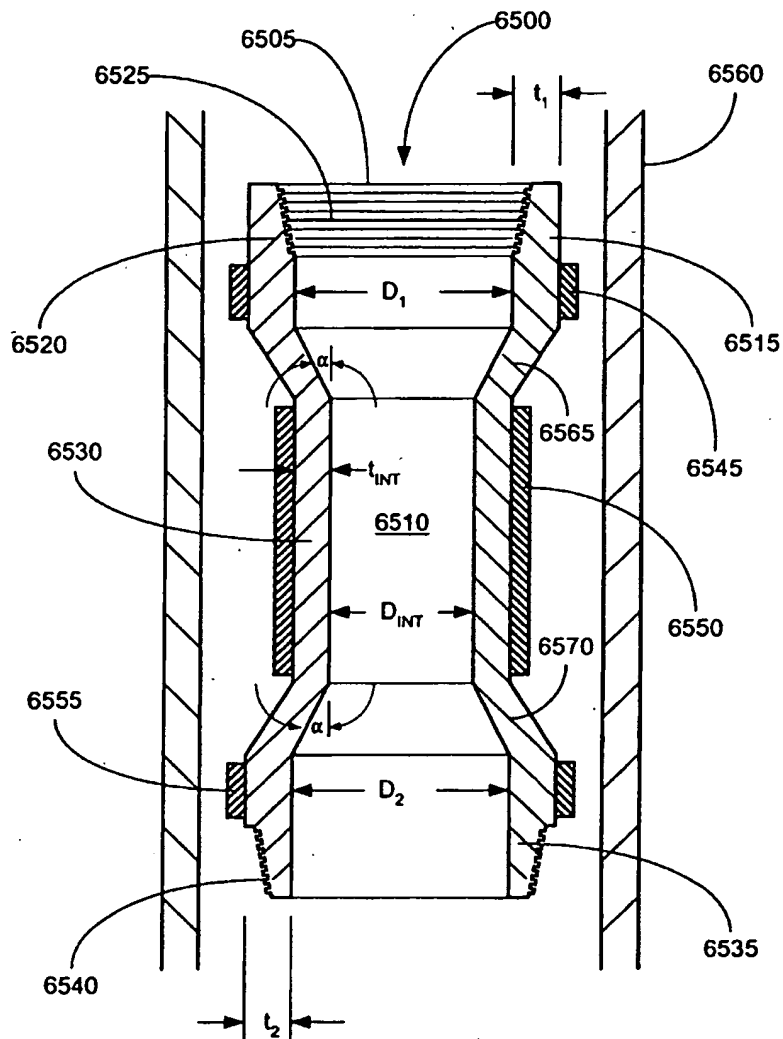


FIGURE 48

WO 01/04535

PCT/US00/18635

77/83

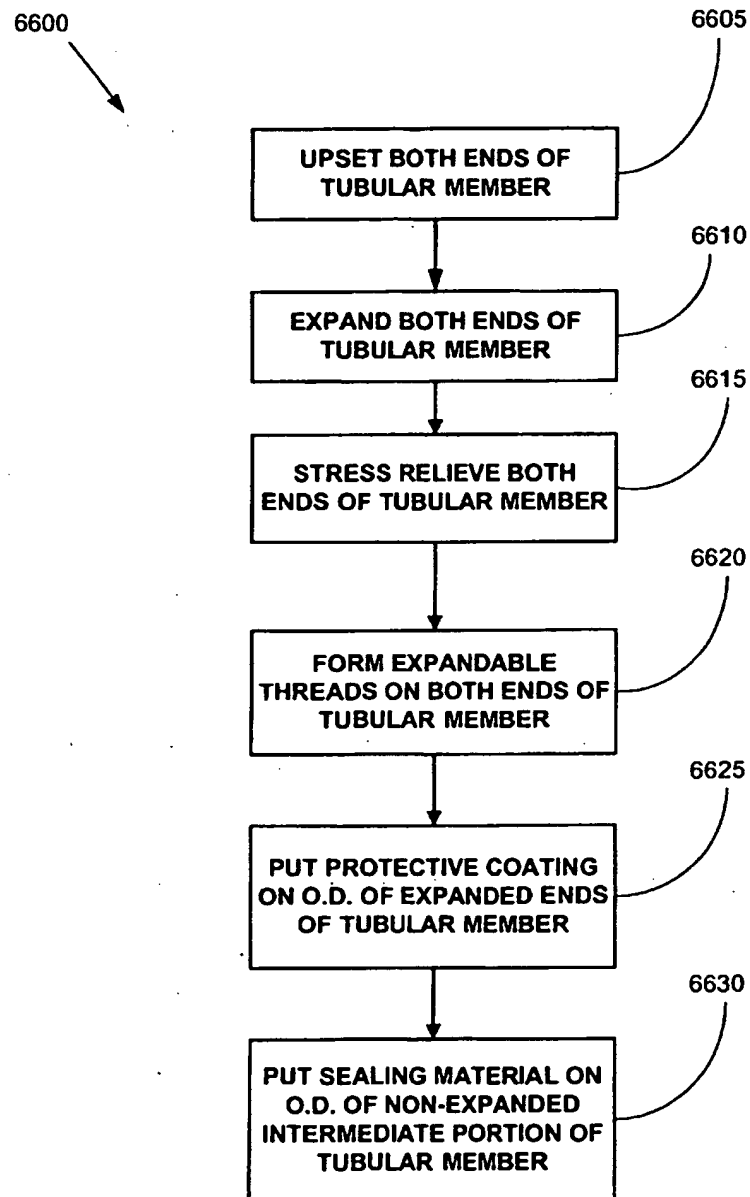


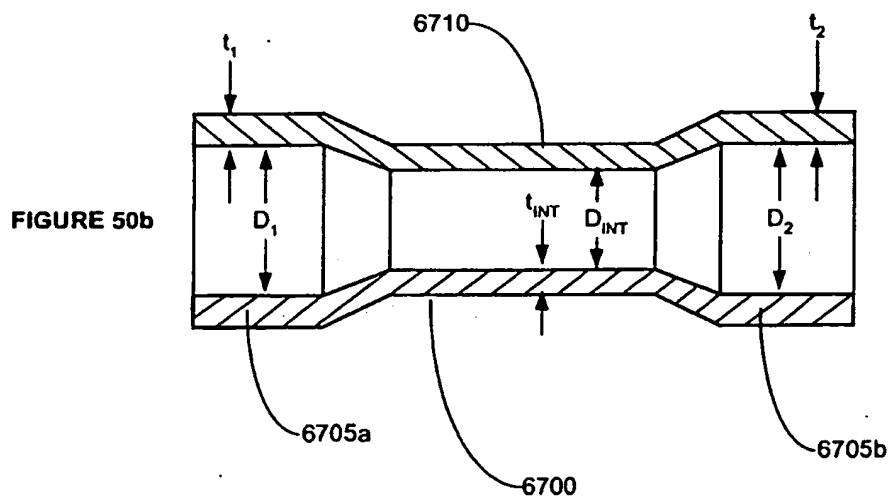
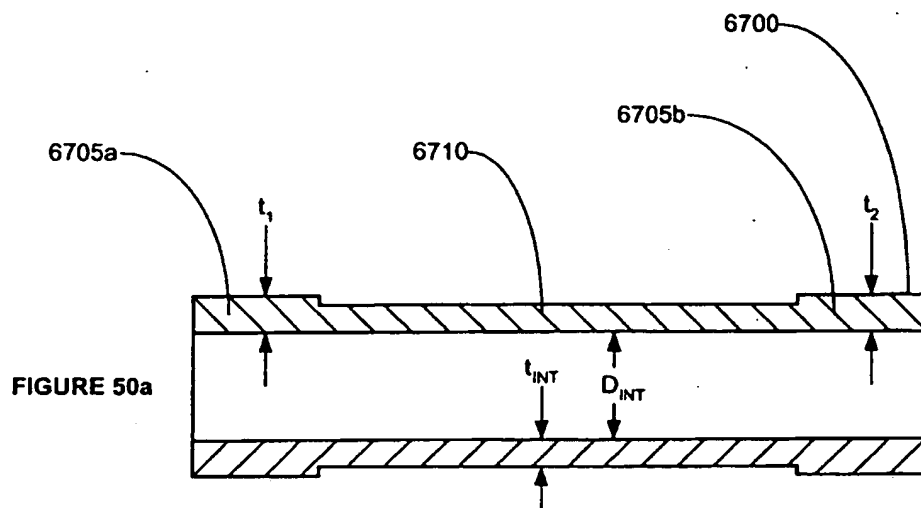
FIGURE 49



WO 01/04535

PCT/US00/18635

78/83



WO 01/04535

PCT/US00/18635

79/83

FIGURE 50c

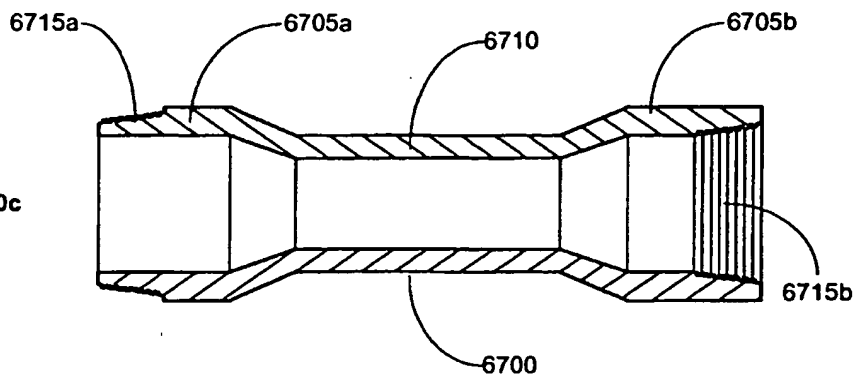


FIGURE 50d

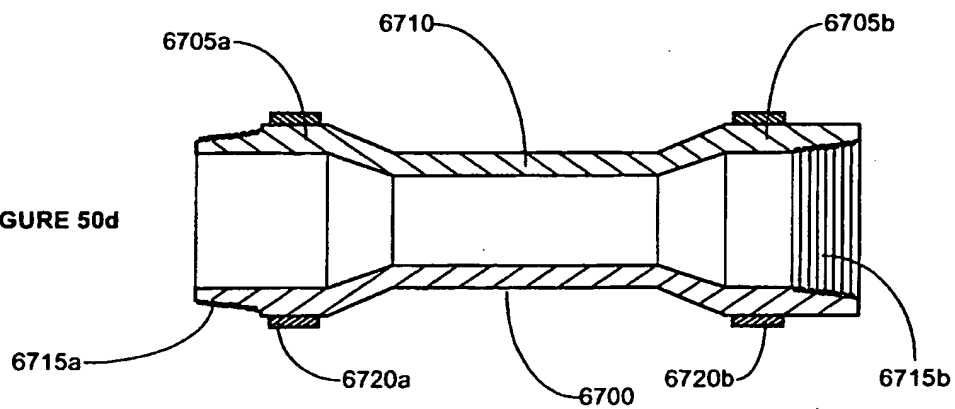
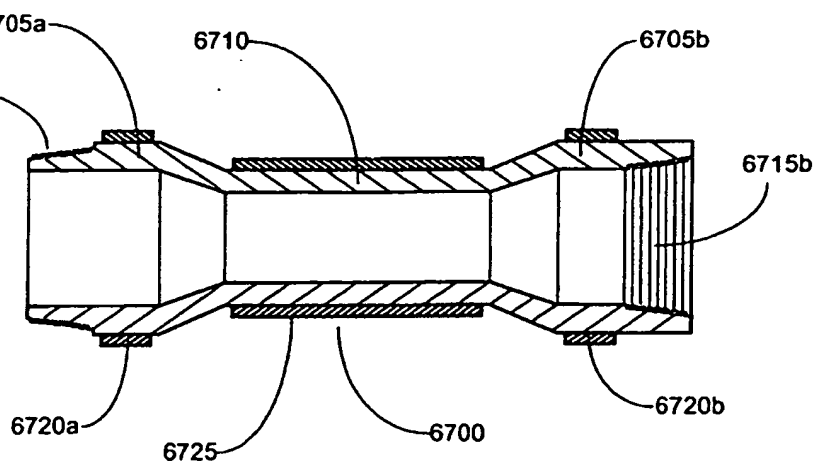


FIGURE 50e



WO 01/04535

PCT/US00/18635

80/83

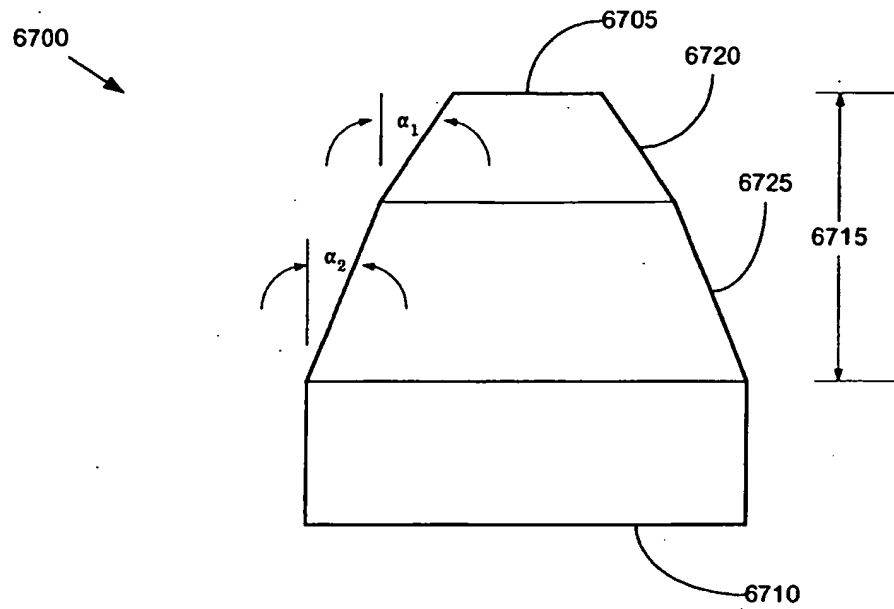


FIGURE 51

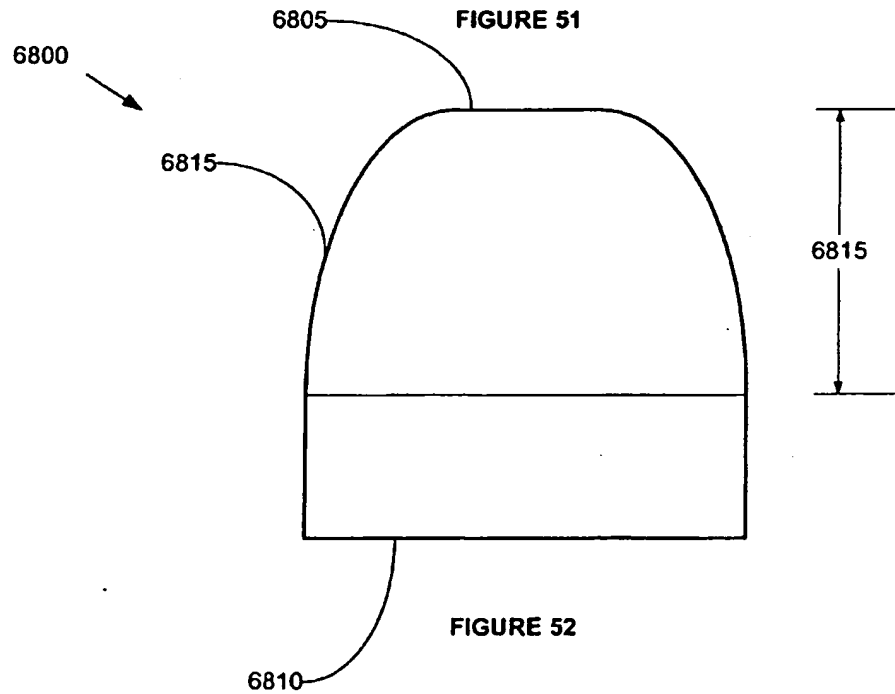


FIGURE 52

WO 01/04535

PCT/US00/18635

81/83

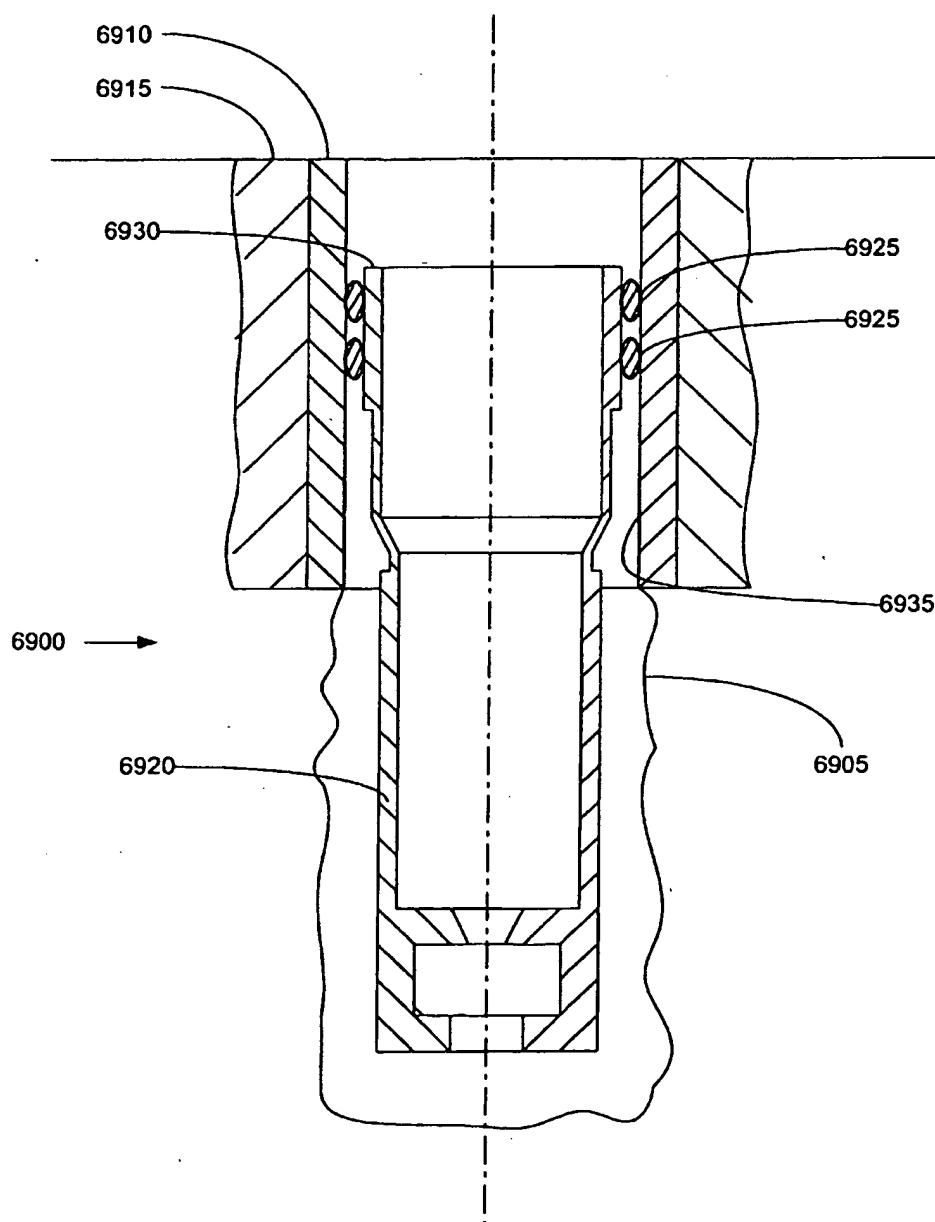


FIGURE 53a

WO 01/04535

PCT/US00/18635

82/83

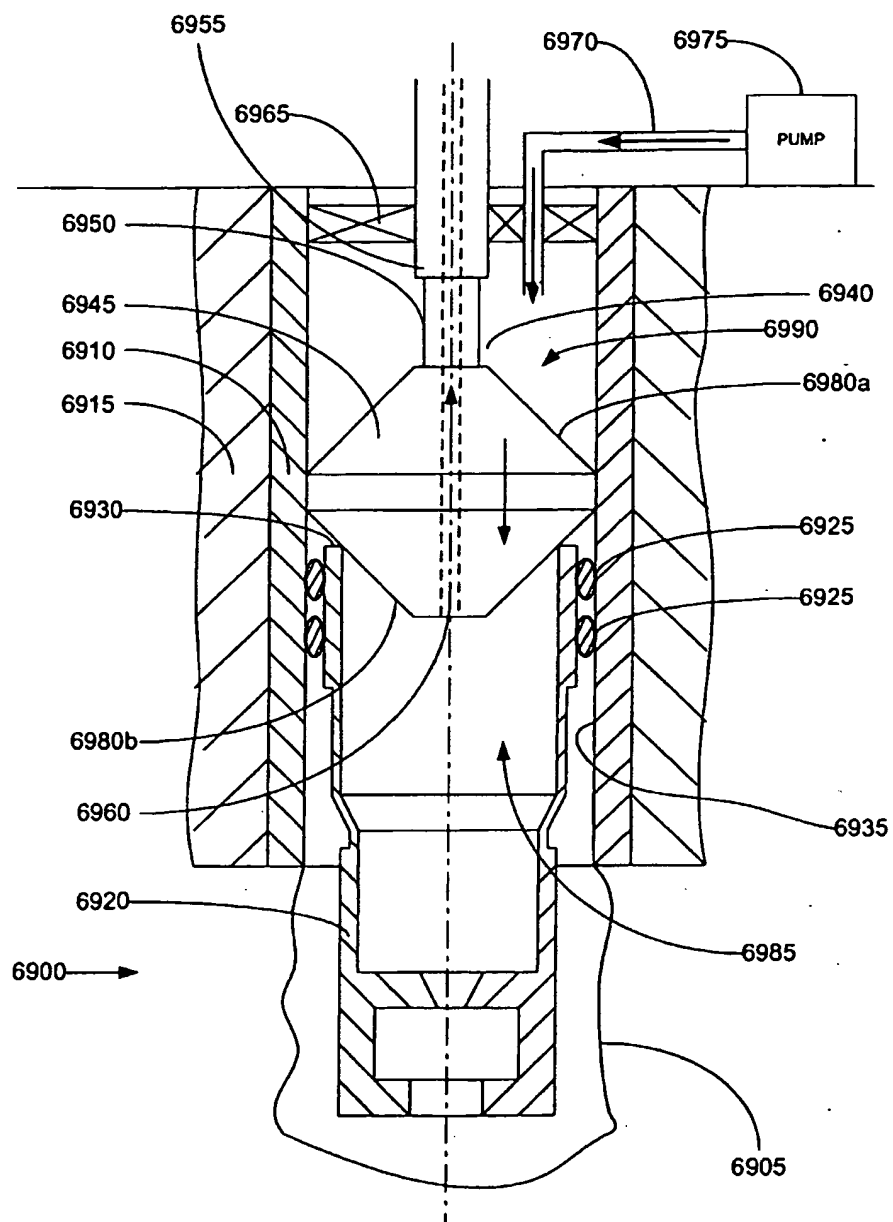


FIGURE 53b

WO 01/04535

PCT/US00/18635

83/83

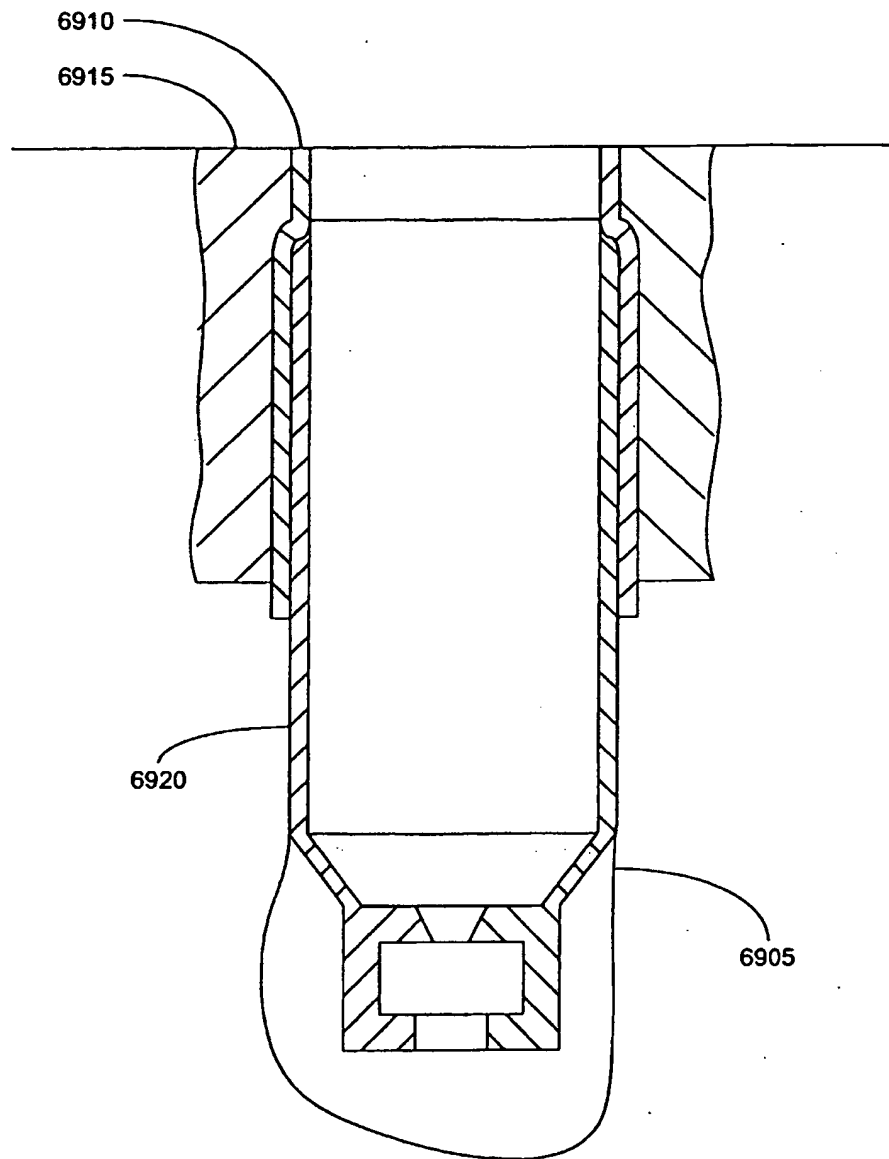


FIGURE 53c

**This Page is Inserted by IFW Indexing and Scanning  
Operations and is not part of the Official Record**

**BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☒ **BLACK BORDERS**
- ☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- ☐ **FADED TEXT OR DRAWING**
- ☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- ☐ **SKEWED/SLANTED IMAGES**
- ☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- ☐ **GRAY SCALE DOCUMENTS**
- ☒ **LINES OR MARKS ON ORIGINAL DOCUMENT**
- ☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- ☐ **OTHER:** \_\_\_\_\_

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**